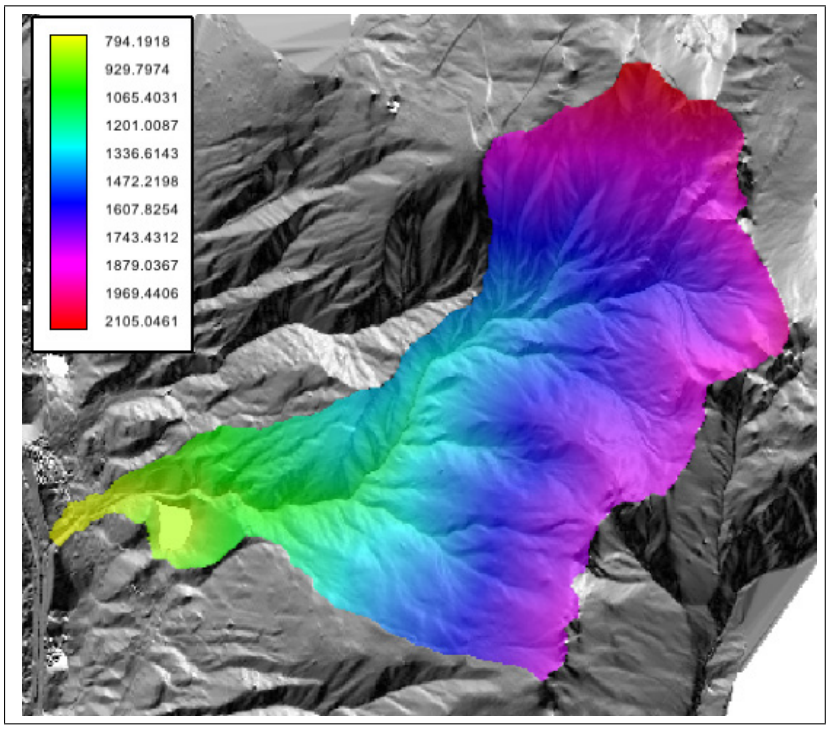
A Tutorial for Preparing GEOtop Input Files with JGrass

Erica Ghesla & Riccardo Rigon



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Readme

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1 Introduction

1.1 JGrass

JGrass is a GIS based mainly on the analysis of raster and contains innovated algorithms for the analysis of landscape shapes necessary in order to delineate the hydrogeological risk zones. In JGrass have been moreover implemented hillslope stability models of stability and floods generation models.

1.2 GEOtop

GEOtop [5, 11, 9], came to be through the will of Riccardo Rigon and in order to answer to a series of converging topics: the desire to model evapotranspiration and eco-hydrological phenomena, slope stability [7] and slope hydrology in general [12], as well as snow cover evolution [6, 8].

GEOtop is a *terrain-based* model, it is in fact based on the use of digital terrain models and exploits the knowledge of the interactions between river basin morphology and basin processes. It is a *distributed* model, all the simulated variables are returned for every pixel of the basin. It is a *hydrological* model, it simulates all the components of the hydrological cycle, not only the water budget but also the energy budget, the two budget equations are coupled by the evapotranspiration and soil temperature terms, the soil temperature term also controls the hydraulic conductivity of the soil and snow cover accumulation [6]). The model has been applied in the study of the hydrological cycle of the Serraia Lake (Trento) [14] and to the data of the SGP97 experiment [5], the model was validated with these data. A complete description of the model is found in [5] and [13], while [4] contains an analysis of the effects of topography in the redistribution of hydrological flows.

For further information please refer to the literature listed in the bibliography and, if necessary, to Rigon's presentation [2004] [10].

The present tutorial has been written to facilitate the procedures of preparation of the geographic spatial inputs for the hydrological model GEOtop. Through the use of the GIS JGrass it is possible to run easely advance analyses for the creation of maps which: water-drainage directions, total contributing areas, channel network, map of the convexities, slopes, aspect and others important geomorfological parameters. These quantities are necessary inputs for the simulation of the hydrological cycle by mass and energy budgets.

2 Preliminary Operations

2.1 Installation of JGrass

The JGrass installation package can be found at the *www.hydrologis.com* web site, in the JGrass section. For information about installation please refer to the aforementioned web site, the *JGrass User Manual* [1], and the JGrass Wiki site. For particular problems you can consult the mailing list, the address is available at the *www.hydrologis.com* web site.
The first steps to take include:

- understanding the JGrass interface;
- understanding what a location is;
- understanding what a digital terrain model (DTM) is ;
- understanding what is the active working region and how to set it up.

All these concepts are explained in detail in the *JGrass User Manual* [1], there follows here only a brief summary.

2.2 Creating of a New Location

Once the program has been installed, it is necessary to create a workspace, also called *location*. The location will contain information relative to the region and the processed maps will be saved therein. For instructions on how to create a new location please refer to the *JGrass User Manual* [1].
Once the location has been created it is possible to access the new workspace, from the main menu select:

$$File \Rightarrow Load\ Workspace$$

or else click directly on the icon as shown in figure 2.2.
In both cases a dialog box will appear from which to select a working mapset. Click on the name of the desired working location (in the example shown the location is *flan_geotop*) and then click the *Finish* button. An example of this operation is shown in figure 2.3. The workspace will appear, as partially shown in figure 2.4.

Figure 2.1: *Accessing a mapset from the main menu.*

Figure 2.2: *Accessing a mapset from the toolbar.*

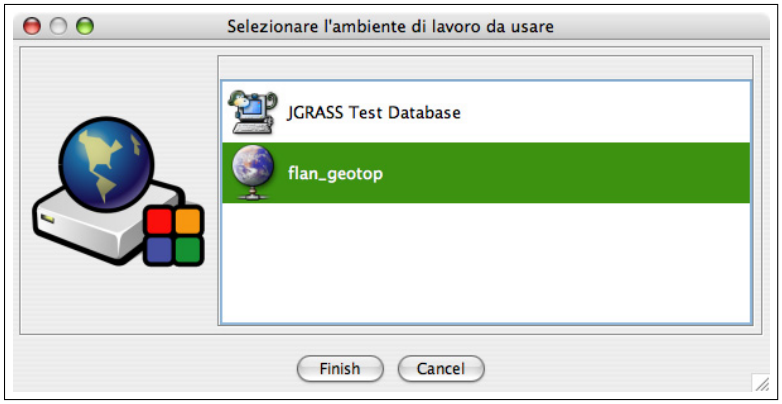

Figure 2.3: *The dialog box for the selection of the workspace from a list of available ones.*

2.3 Importing the DEM (*Digital Elevation Model*)

The first necessary operation is to import the digital terrain data of the area that you wish to analyze into JGrass. The imported DEM is the basis from which the maps necessary for the execution of GEOtop are generated.
The command to execute is *r.in.ascii*, from the main menu select:

$$Gis \Rightarrow Import/Export\ Tools$$

as shown in figure 2.4.

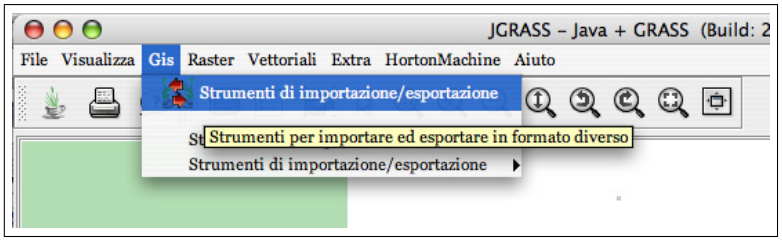
JGRASS - Java + GRASS (Build: 2
File Visualizza Gis Raster Vettoriali Extra HortonMachine Aiuto
Strumenti di importazione/esportazione
Strumenti per importare ed esportare in formato diverso
Strumenti di importazione/esportazione

Figure 2.4: *Importing digital data into JGrass.*

In so doing a new toolbar appears, shown in figure 2.5. To view the importation command dialog box, click on the icon as shown in figure 2.5.

Figure 2.5: *The icon to click in order to import digital data into JGrass.*

The command can also be executed by selecting:

$$Gis \Rightarrow Import/Export\ Tools \Rightarrow r.in.ascii$$

as shown in figure 2.6.

Figure 2.6: *Importing digital data into JGrass.*

2.3.1 Example

Let us import the DEM of interest, it is the starting point for the generation of the input files necessary for the execution of the *GEOtop* program. Figure 2.7 shows the dialog box where the file to be imported is selected. Click on the *Browse* button to select the file to be imported. The program requires you to specify the value that has been assigned to the *null value* points of the map to be imported, in the example it is *-9999* (when the value of a point of the map is unknown, these are assigned either a number or a symbol so that they can be recognised. In many cases the asterisk, *, is used or another symbol. In these cases JGrass requires you to specify the null value so that it can distinguish it from points of known value). Specify a name to give to the imported map within JGrass. Click *ok* in order to execute the command. In this way the map will be imported.

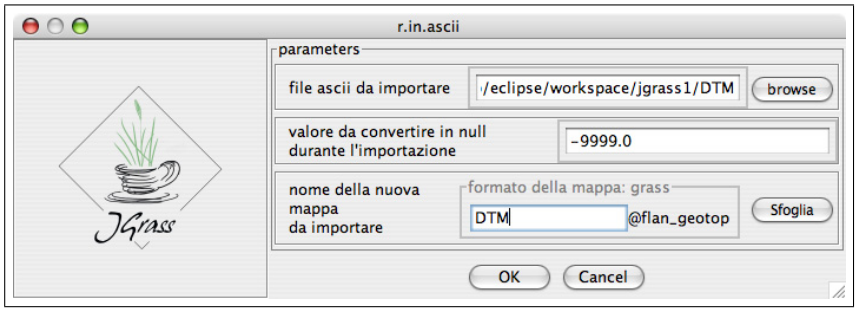

Figure 2.7: *r.in.ascii. Dialog box for the selection of the file to import to JGrass.*

2.3.2 Execution from the Command Line

The JGrass commands can be executed directly from the command line without viewing the dialog box. To view the console click the icon as shown in figure 2.8.

Figure 2.8: *The icon to click in order to view the console.*

Figure 2.9: *The JGrass Console.*

To execute programs from the "command line" you need to know the syntax to use. If you are unsure of the exact syntax it is sufficient to type "*command name –usage*" and then hit *enter*, the string to use will appear on the console. The execution of *r.in.ascii* from the comand line is shown in figure 2.10:

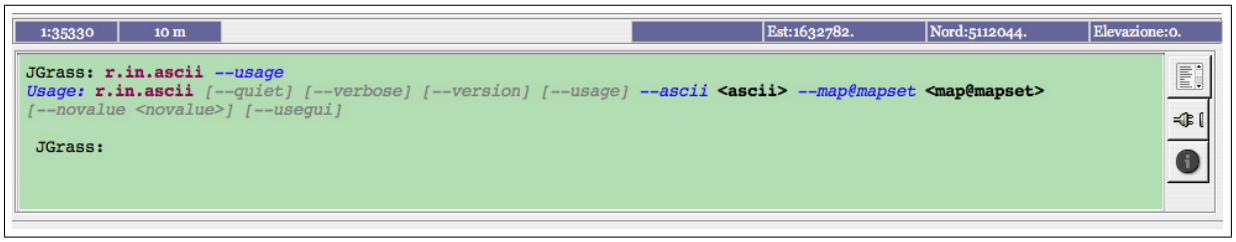

Figure 2.10: *Execution of the r.in.ascii command from the command line.*

- *[–quiet]*: allows you to follow the evolution of the command;
- *[–verbose]*: shows the entire evolution of the command and the internal console messages, this option can also be activated with the information icon of the console;
- *[–usage]*: allows you to view the syntax that is to be used in order to execute a command (you must write: *r.in.ascii –usage*), this string must not be included for the execution of the command;
- *–ascii <ascii>*: the map to be imported, the string *<ascii>* is to be replaced with the name of the map to be imported;
- *–map@mapset <map@mapset>*: name to be assigned to the new map and the mapset where it will be saved, the string *<map@mapset>* is to be replaced with the name of the map (*map*) and the mapset (*@mapset*) where it is to be saved;
- *[–novalue <novalue>]*: value to be assigned to the "null value" points, this term is not strictly necessary, if it is not specified the program will automatically assign the value of -9999.0;
- *[–usegui]*: allows you to view the dialog box of the command (you must write *r.in.ascii –usegui*), this string must not be included for the execution of the command;

to execute *r.in.ascii*, as in the example in paragraph 2.3.1, it is sufficient to write:
r.in.ascii *–ascii* /Users/erica/Desktop/eclipse/workspace/jgrass1/DTM *–map@mapset* DTM@flan_geotop

For further information on the use of the console please refer to the *JGrass User Manual*, [1].

2.4 Setting Up the Active Working Region

Before viewing the imported map it is necessary to set up the active working region. This procedure allows you to assign the coordinates and resolution of the imported map to the display screen. The command to execute is *g.region*, from the main menu select:

Gis ⇒ *Region Tools* ⇒ *Region Manager*

as shown in figure 2.11. A dialog box will appear where the information about to the region is input, an example is shown in figure 2.12.

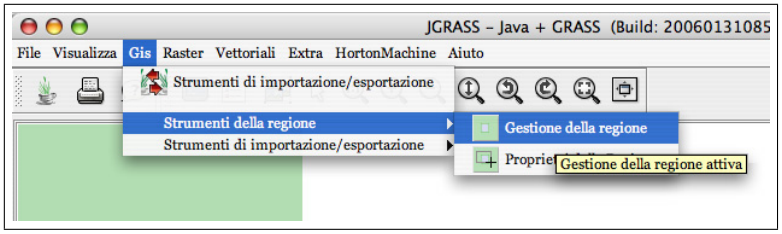
JGRASS - Java + GRASS (Build: 20060131085
File Visualizza Gis Raster Vettoriali Extra HortonMachine Aiuto
Strumenti di importazione/esportazione
Strumenti della regione
Strumenti di importazione/esportazione
Gestione della regione
Gestione della regione attiva

Figure 2.11: *The* g.region *icon*

The *g.region* command can be executed from the console command line:
g.region [–quiet] [–verbose] [–version] [–usage] –west <west> –east <east> –north <north> –south <south> –map <map> –resolution <resolution> [–default] [–usetoolbar] [–usegui]

2.4.1 Example

To set up the working region, click the icon, as explained in paragraph 2.11. The name of the map of interest can be input directly into the specific text box, which is found in correspondence of the string "*map selection*", or else by clicking the *Browse* button and then selecting from the list of available maps. Once a map has been selected click the "*set region from map*" button in order to set up the region. The information relative to the region will then appear, as shown in figure 2.12.
It is important that a lot of attention be given to this operation as all the calculations that will be carried out afterwards depend on a correct setup of the working region. It is necessary to verify that the numbers which indicate the resolution (found in the text boxes beside the strings *nsres*, pixel dimension in a north-south direction, and *ewres*, pixel dimension in an east-west direction) be integers. If necessary, modify the coordinates of the region boundary so as to obtain whole number values for the resolution (the coordinates can be modified so that the difference between the North-South and the East-West coordinates be multiples of the pixel resolution).

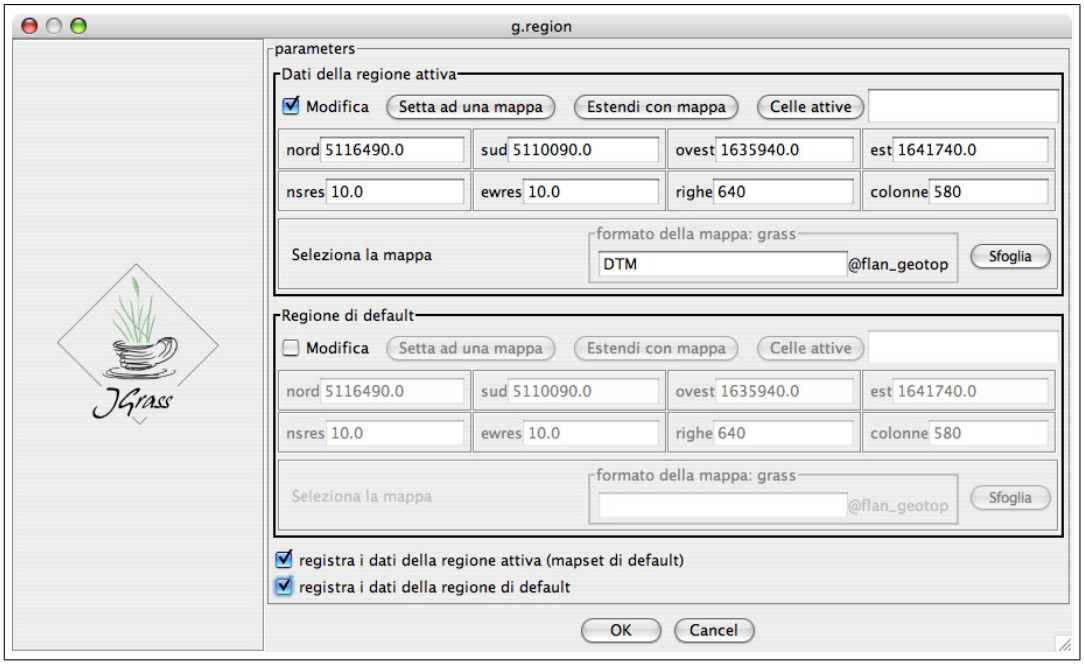

Figure 2.12: *The* g.region *dialog box*

2.5 Viewing the Imported Map

Once the map has been imported and the working region has been set it will be possible to view the map and verify that all the operations have been carried out correctly. To view the imported map, from the main menu, select:

View ⇒ *Display a raster map*

as shown in figure 2.13.

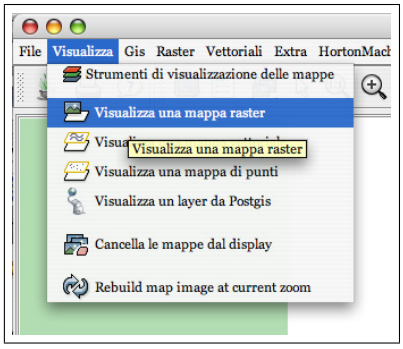

Figure 2.13: *Displaying a map in JGrass.*

The map can also be viewed by selecting :

View ⇒ *Map Display Tools*

as shown in figure 2.14. In this case a new toolbar appears, click on the first icon, a display wizard will appear from where the map to display can be selected, figure 2.15.

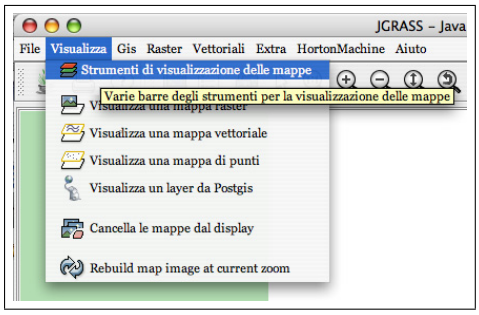

Figure 2.14: *Selecting the toolbar with the* d.rast *command icon.*

The result of the procedure is shown in figure 2.16.

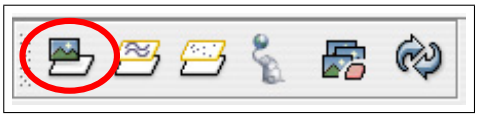

Figure 2.15: *Displaying a map in JGrass.*

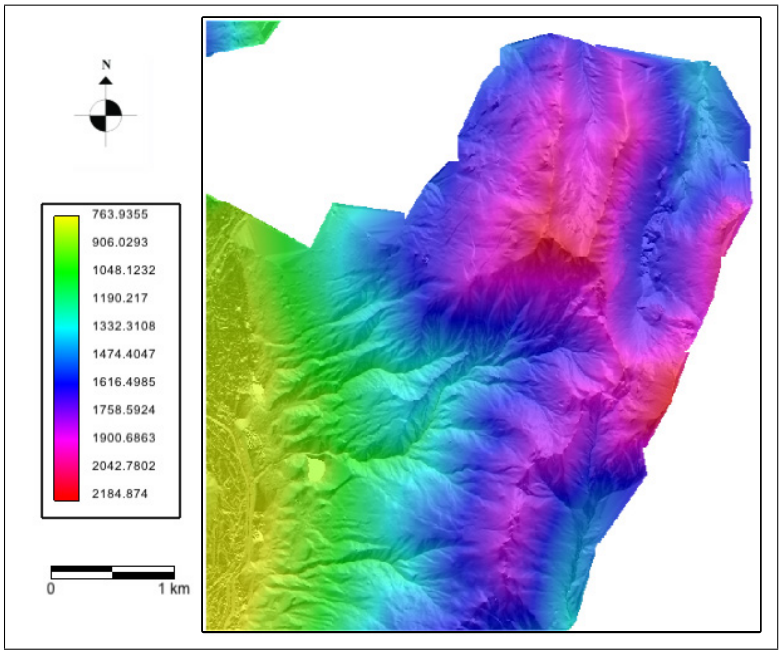

Figure 2.16: *The result of the importation process. DEM of the Flanginec Basin.*

3 Data Preprocessing for the Extraction of the Hydrographic Basin

In order to extract the hydrographic basin of interest, some processing of the original digital data of the land area containing the basin is necessary. The processing operations include eliminating the pits (*Pitfiller*), calculating the drainage directions (*Flowdirections* and *Draindir*), and the extraction of the hydrographic network (*Extractnetwork*).

3.1 Pitfiller

Pitfiller eliminates possible points of depression, thus the drainage directions can be calculated correctly. The command to execute is *h.pitfiller*. To launch it, from the main menu select:

$$HortonMachine \Rightarrow DEM\ manipulation \Rightarrow h.pitfiller$$

as shown in figure 3.1.
The command can also be launched by clicking the corresponding icon from the toolbar that appears by checking:

$$HortonMachine \Rightarrow DEM\ manipulation$$

as shown in figures 3.2 and 3.3.

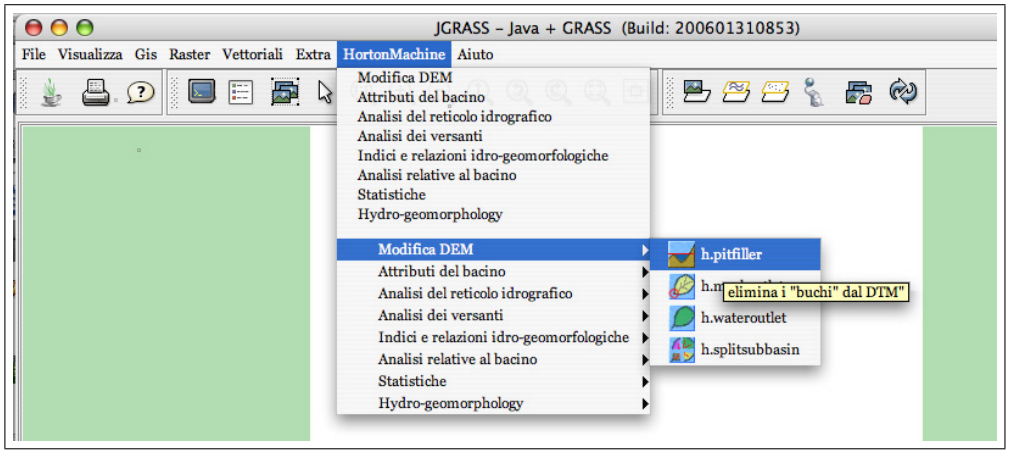

Figure 3.1: *Executing the* h.pitfiller *command.*

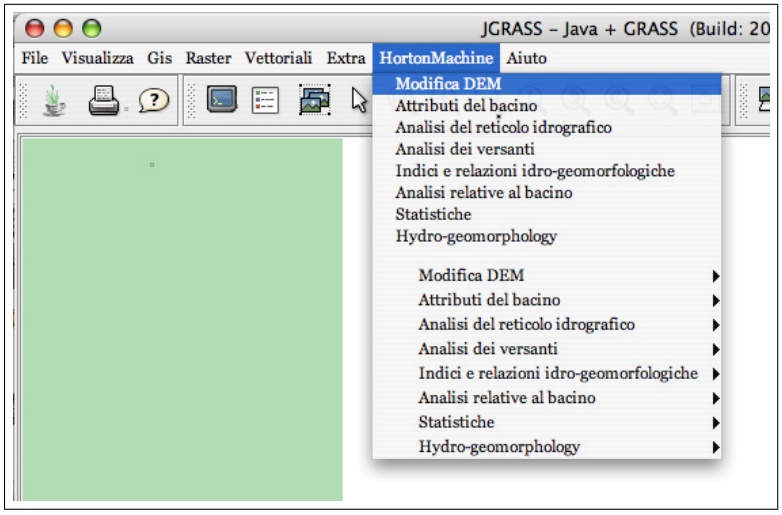

Figure 3.2: *Executing the* h.pitfiller *command.*

Figure 3.3: *The* h.pitfiller *icon.*

In both cases a dialog box will appear on display. From dialog box you select the input map to be used for the calculation and choose a name for the output map that will be calculated, as shown in figure 3.3.

The *h.pitfiller* command can also be executed from the console command line:

h.pitfiller [–quiet] [–verbose] [–version] [–usage] –elevation <elevation> –inmapset <inmapset> [–inputformat <inputformat>] –pit <pit> –outmapset <outmapset> [–outputformat <outputformat>] [–usegui].

3.1.1 Example

There now follows an example of application to a real situation. The DEM that was previously imported is now required as input. In the specific case the file to input is called DTM. The (depitted) output file is "*pit.test*". The string @*flan_test* which follows the map name refers to the working "*location*".

By clicking *ok* the *h.pitfiller* command is launched. (For greater clarity during map management it is advised to give the maps names that refer to the command used to produce them.) At this point it is possible to view the resulting map,*pit_test*. For a description of the display method and and for the creation of a map legend please refer to the JGrass Manual [1]. Figure 3.5 shows the

resulting map.

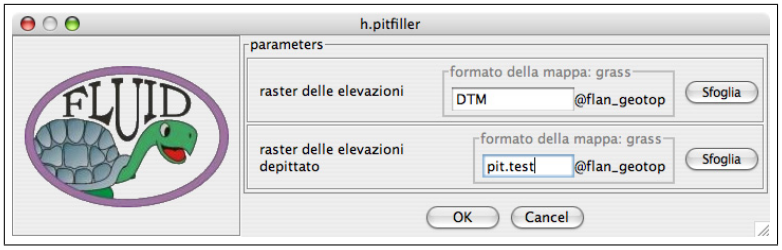

Figure 3.4: *h.pitfiller. Dialog box where the names of the input and output maps are specified.*

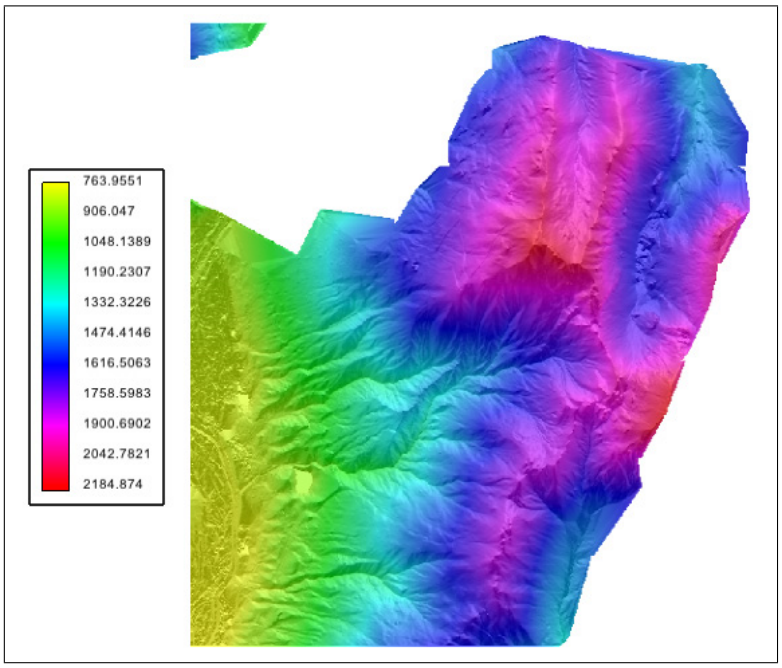

Figure 3.5: *h.pitfiller. Depitted elevation map. The Flanginec Basin.*

3.2 FlowDirections

The following step is to determine how water moves on the surface in relation to the topography that characterizes the region in question. The *Flowdirections* command calculates the drainage directions. The exact identification of the natural path is limited due to the way in which the Earth's surface is discretized. There are, in fact, only 8 possible directions in which the flow can be directed. *Flowdirections* identifies the drainage direction by directing the flow along the line of maximum slope, according to the D8 scheme. In figure **??** the adopted convention for the numbering of the 8 possible flow directions is represented.
The command to execute is*h.flowdirections*, from the main menu select:

HortonMachine ⇒ *Basic topographic attributes* ⇒ *h.flowdirections*

or else click the corresponding icon from the toolbar that appears by checking:

HortonMachine ⇒ *Basic topographic attributes.*

Figure 3.6 shows the toolbar with the *h.flowdirections* icon. The legend of figure 3.8 highlights the fact that only 8 drainage directions are possible.

Figure 3.6: *The* h.flowdirections *icon.*

The *h.flowdirections* command can also be launched from the console command line:
h.flowdirections [–quiet] [–verbose] [–version] [–usage] –pit <pit> –pitmapset <pitmapset> [–pitformat <pitformat>] –flow <flow> –flowmapset <flowmapset> [–flowformat <flowformat>] [–usegui].

3.2.1 Example

In the example that follows you will be shown how to launch the command. The depitted DEM calculated with *h.pitfiller*, paragraph 3.1, is required as input. Figure 3.7 shows the dialog box where the names of the input and output maps are specified.

Figure 3.7: *h.flowdirections. Dialog box where the names of the input and output maps are specified.*

Once the processing has finished it is possible to view the resulting output map, (figure 3.8):

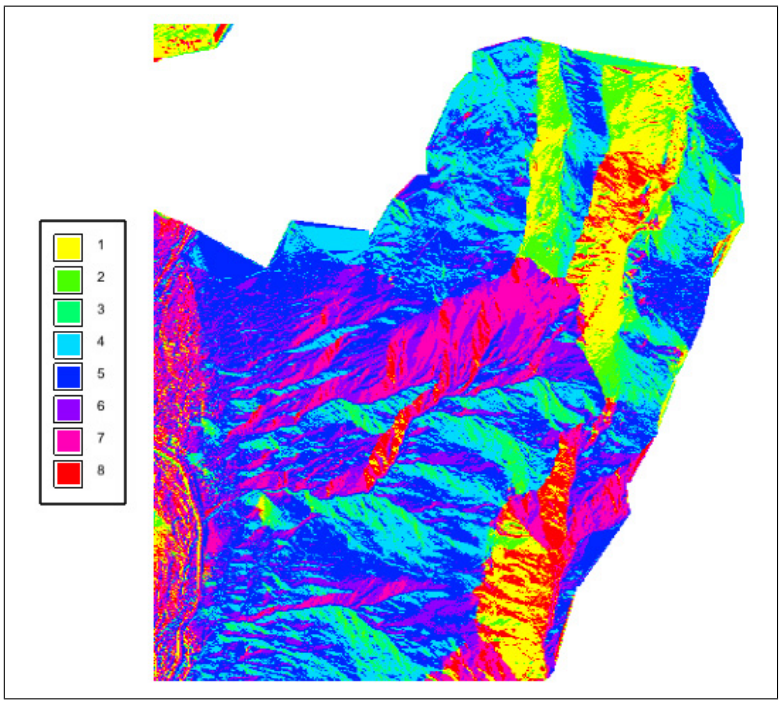

Figure 3.8: *h.flowdirections. Drainage directions map. The Flanginec Basin.*

3.3 DrainDir

The method used in *Flowdirections* to calculate the drainage directions causes a deviation of the flow with respect to the real path taken by the water on its descent downstream, [Orlandini et al., 2003]. The *Draindir* command recalculates the flow path with a correction that minimizes the deviation.

The program also calculates the contributing areas (*TCA or Total Contributing Area*) which represent the projection onto a horizontal plane of the areas that contribute to a point of the basin. The calculation of this quantity is done by following the drainage directions from every point of the basin and then cumulating the area along the paths determined by the drainage directions. For further details about the method used, please refer to *The Horton Machine* [2] and the article by *Orlandini et al. [2003]* [15].

The command to execute is *h.draindir*, from the main menu select:

HortonMachine ⇒ *Basic topographic attributes* ⇒ *h.draindir*

or else click the corresponding icon from the toolbar that appears by checking:

HortonMachine ⇒ *Basic topographic attributes*

The toolbar with the *h.draindir* icon is shown in figure 3.9.

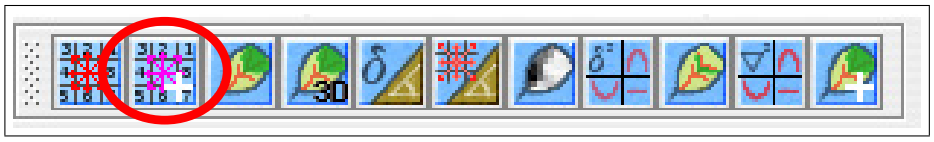

Figure 3.9: *The* h.draindir *icon.*

The command gives you a choice of the calculation method to use and allows you to fix the hydrographic network if this is known. For details regarding the calculation methods (*LAD and LTD*) and the parameters to be input refer to *The Horton Machine* [2].

The *h.draindir* command can also be executed from the console command line:

h.draindir [–quiet] [–verbose] [–version] [–usage] –pit <pit> –pitmapset <pitmapset> [–pitformat <pitformat>] –flow <flow> –flowmapset <flowmapset> [–flowformat <flowformat>] [–net_fixed <net_fixed>] [–net_fixedmapset <net_fixedmapset>] [–net_fixedformat <net_fixedformat>] –draindir <draindir> –draindirmapset <draindirmapset> [–draindirformat <draindirformat>] [–tca <tca>]

[–tcamapset <tcamapset>] [–tcaformat <tcaformat>] –mode <mode> –netmode <netmode> –lambda <lambda> [–usegui].

3.3.1 Example

The graphic interface for the *h.draindir* command is shown in figure 3.10.

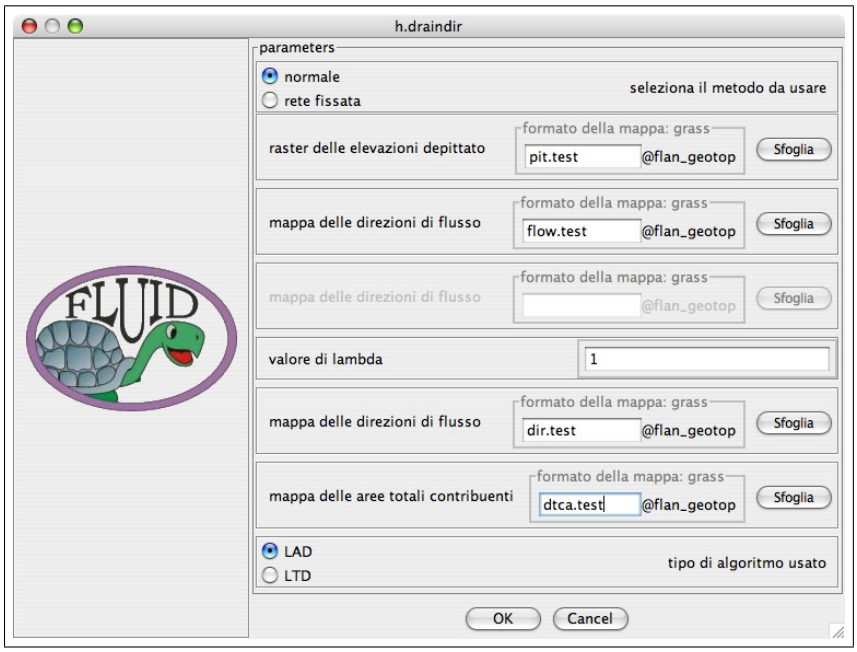

Figure 3.10: *h.draindir. Dialog box where the names of the input and output maps are specified.*

In the example, the drainage directions are calculated without fixing the hydrographic network beforehand, select the *normal* method (for the execution of the command in *net fixed mode* refer to the JGrass Tutorial [3]). The required input data are the depitted DEM, calculated with *h.pitfiller*, and the drainage directions map, calculated with *h.flowdirection*. Furthermore, it is necessary to assign a value to the λ parameter, this parameter assigns a weight to the correction made on the drainage directions (the value assigned must be within 0 and 1). You must also choose the algorithm type used to carry out the calculation (*LAD*, least angular deviation, which calculates the angular deviation with respect to the real flow path or *LTD*, least transversal deviation, which calculates the transversal deviation). In the example the *LAD* method is used and the the λ parameter was assigned a value of 1 (in this way the calculated correction is fully taken into account). For further details about the methods and the parameters please refer to *The Horton Machine* [2] and the article by *Orlandini et al. [2003]* [15]. The results obtained are shown in figure 3.11, the corrected

drainage directions, and figure 3.12, the contributing areas.

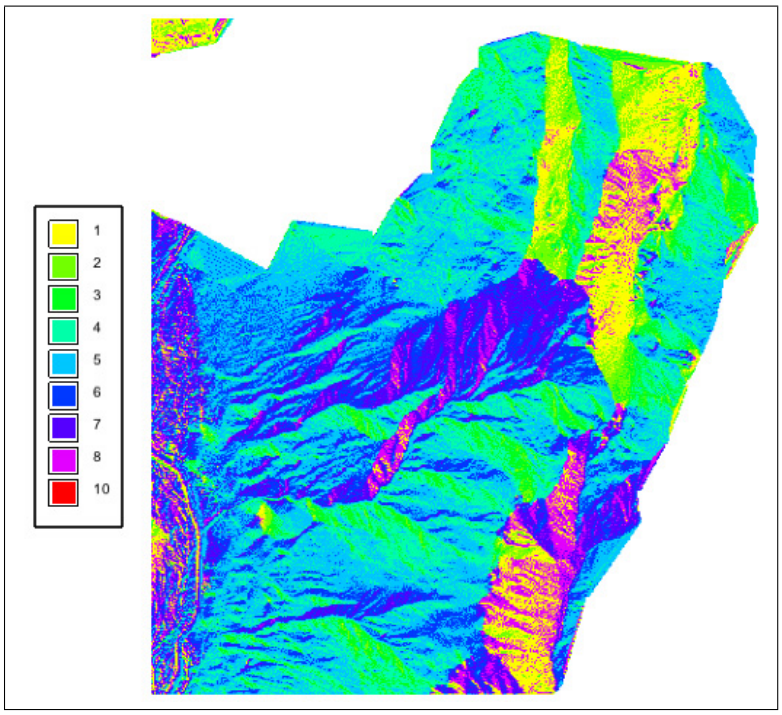

Figure 3.11: *h.draindir. Map of the corrected drainage directions. The Flanginec Basin.*

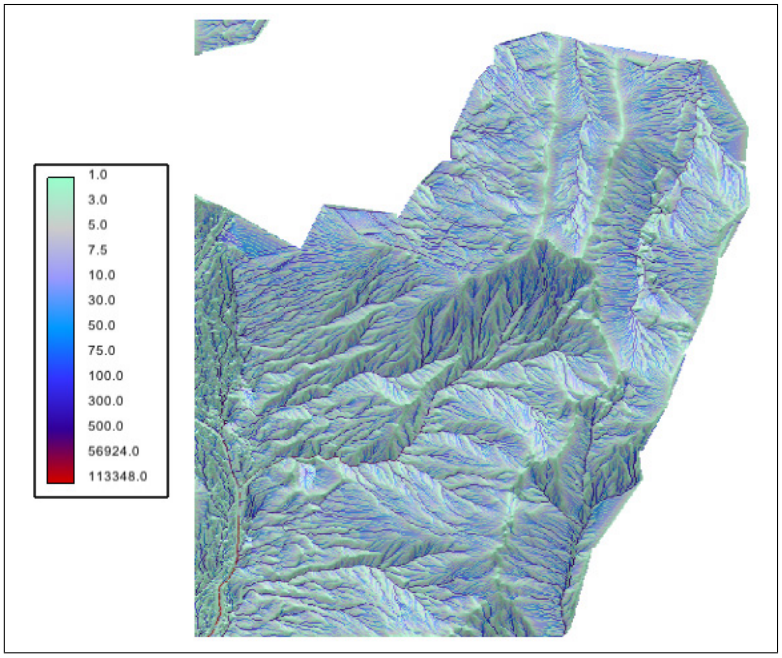

Figure 3.12: *h.draindir. Total contributing areas map based on the corrected drainage directions. The unit of measurement is pixels. The Flanginec Basin.*

3.4 MarkOutlets

At this stage it is necessary to mark all the outlets of the considered region on the drainage directions map. Indeed, by following the drainage directions you will eventually reach the border of the DEM. These points on the border can in fact be the closing sections of a basin. *MarkOutlets* identifies these points. A convention has been adopted by which the drainage direction value of these points is replaced with 10. This operation is of fundamental importance for the calculation of other quantities. During the following processing operations reference will always be made to the drainage directions map with marked outlets, even if not specifically stated.
The command to execute is *h.markoutlets*. To do so, from the main menu select:

HortonMachine ⇒ *DEM manipulation* ⇒ *h.markoutlets*

or else click the corresponding icon from the toolbar that appears by checking:

HortonMachine ⇒ *DEM manipulation*

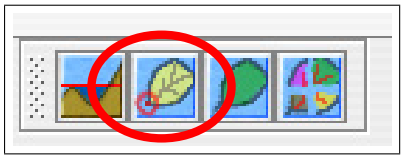

Figure 3.13: *The* h.markoutlets *icon.*

The *h.markoutlets* command can also be executed from the console command line:
h.markoutlets [–quiet] [–verbose] [–version] [–usage] –flow <flow> –inmapset <inmapset> [–inputformat <inputformat>] –mflow <mflow> –mflowmapset <mflowmapset> [–mflowformat <mflowformat>] [–usegui].

3.4.1 Example

The command's graphic interface is shown in figure 3.14. The drainage directions map is required as input. The result is shown in figure 3.14.

Figure 3.14: *h.markoutlets. Dialog box where the names of the input and output maps are specified.*

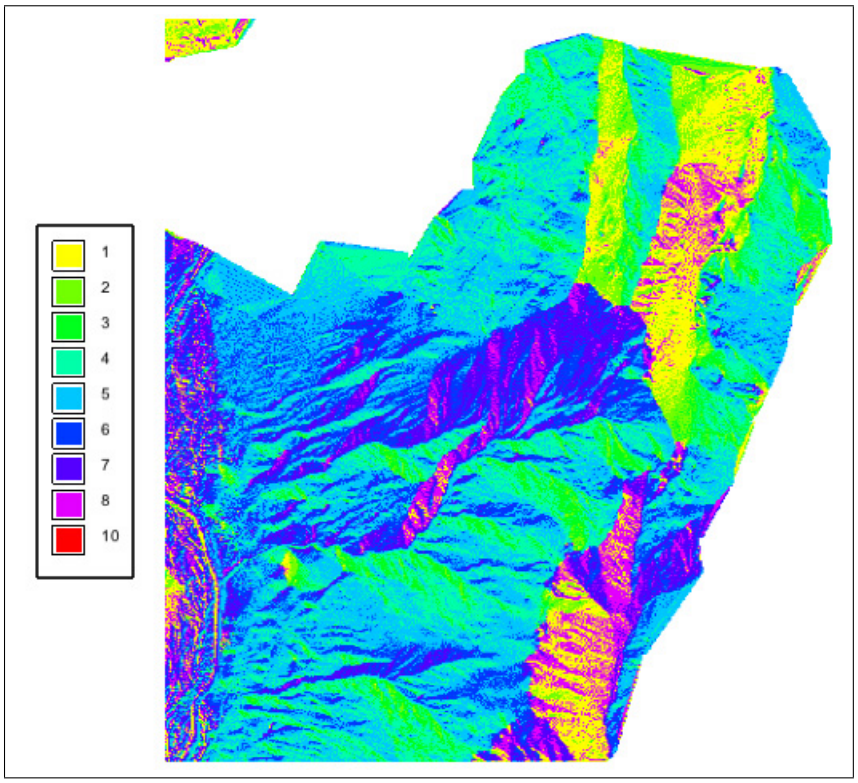

Figure 3.15: *h.markoutlets. Corrected drainage directions map with the region outlets marked. The Flanginec Basin.*

3.5 ExtractNectwork

The hydrographic network can now be extracted with one of the three methods available. The first method is based on the magnitude or the total contributing area, the second is based on the product of the total contributing area and the gradient, the third is based on the curvatures. Depending on the method chosen, different additional maps need to calculated. The resulting channel network map will have a value of 2 in correspondence of the network and a "null value" in the other points.
The command to execute is *h.extractnetwork*, from the main menu select:

HortonMachine ⇒ *Network related measures* ⇒ *h.extractnetwork*

or else click the corresponding icon from the toolbar that appears by checking:

HortonMachine ⇒ *Network related measures*

Figure 3.16 shows the toolbar containing the *h.extractnetwork* icon.

Figure 3.16: *The* h.extractnetwork *icon.*

The *h.extractnetwork* command can also be executed from the console command line:
h.extractnetwork [–quiet] [–verbose] [–version] [–usage] –prof_curv <prof_curv> –prof_curvmapset <prof_curvmapset> [–prof_curvformat <prof_curvformat>] –tang_curv <tang_curv> –tang_curvmapset <tang_curvmapset> [–tang_curvformat <tang_curvformat>]–cp3map <cp3map> –cp3mapmapset <cp3mapmapset> [–cp3mapformat <cp3mapformat>] –cp9map <cp9map> –cp9mapmapset <cp9mapmapset> [–cp9mapformat <cp9mapformat>] –th_prof <th_prof> –th_tan <th_tan> [–usegui].
There follow some examples of the execution of the command using the three available methods.

3.5.1 Determination of the Network Using the Contributing Areas (or the Magnitude)

The calculation is done by imposing a threshold on the contributing areas or magnitude. In this method it is assumed that all pixels with a contributing area value greater than the threshold are channel pixels. The choice of the threshold value is made in relation to the characteristics of the land surface and the resolution of the map (pixel size). If not enough information is available to make a reasonable choice for the threshold value, it is advisable to make a number of attempts, changing value each time, and then confront the resulting network with an orthophoto of the basin.

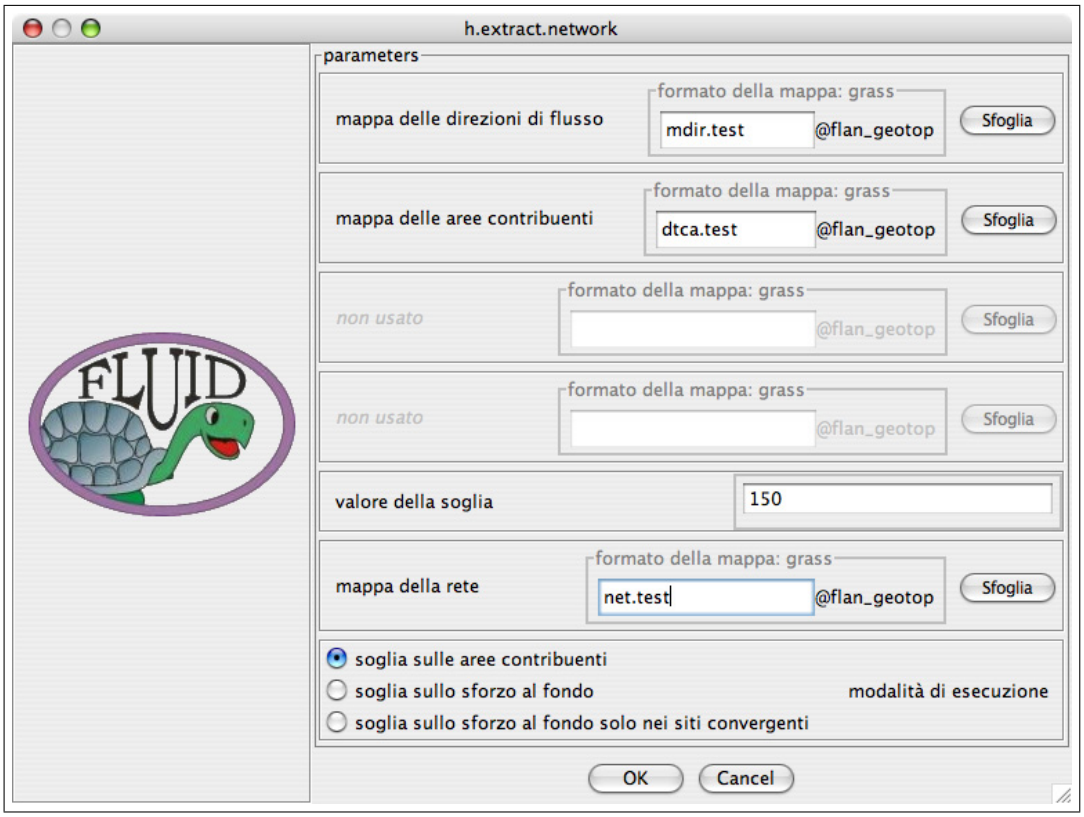

Figure 3.17: *h.extractnetwork. Dialog box where the names of the input and output maps are specified.*

Example

The method to use is chosen by selecting the corresponding option in the lower part of the dialog box, as shown in figure 3.17. The required input data are, in order: the drainage directions map

(with marked outlets), the map upon which the threshold will be imposed. In the example the map used is the total contributing areas map, calculated with *h.draindir*. The threshold value is set to 150 pixels, the map resolution is 10m. Figure 3.18 shows the results of the calculation.

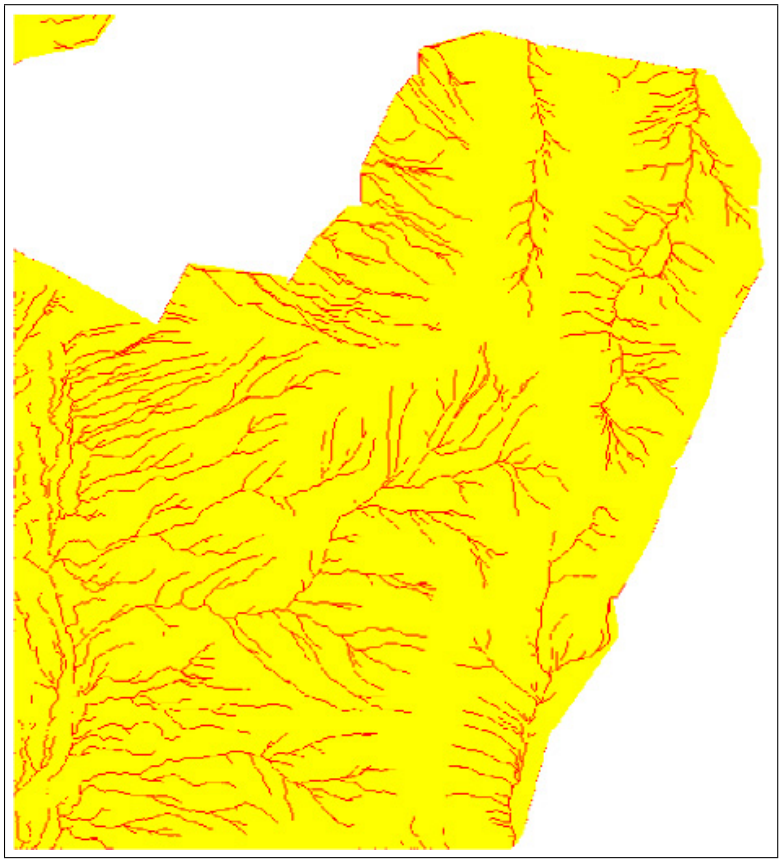

Figure 3.18: *h.extractnetwork. Map of the hydrographic network obtained by imposing a threshold on the contributing areas. The network points are marked in red (assigned value of 2). The map represents an area of the Province of Trento.*

It must be noted that in the resulting map numerous groups of hydrographic networks are identified, each group corresponds to a small basin, as will be seen later.

3.5.2 Determination of the Network Using the Contributing Areas and the Slopes

The calculation is done by imposing a threshold on the product of two quantities, for example, the contributing area and the slope. The first step is therefore the calculation of the slope map. This operation is done with *h.gradient*.

Gradient

The gradient is calculated in each point of the map. The command to execute is *h.gradient*. From the main menu select:

HortonMachine ⇒ *Basic topographic attributes* ⇒ *h.gradient*

or else click the corresponding icon from the toolbar that appears by checking:

HortonMachine ⇒ *Basic topographic attributes*

Figure 3.19 shows the toolbar with the *h.gradient* icon.

Figure 3.19: *The* h.gradient *icon.*

The *h.gradient* command can also be executed from the console command line:
h.gradient [–quiet] [–verbose] [–version] [–usage] –pit <pit> –pitmapset <pitmapset> [–pitformat <pitformat>] –gradient <gradient> –gradientmapset <gradientmapset> [–gradientputformat <gradientputformat>] [–usegui]

Example

The first thing to do is calculate the gradient map, to execute the command click the icon shown in figure 3.19. The depitted elevation map, calculated with *h.pitfiller*, is required as input.
The graphic interface of the *h.gradient* command, where the names of the input and output maps are given , is shown in figure 3.20. Figure 3.21 shows the resulting output map.

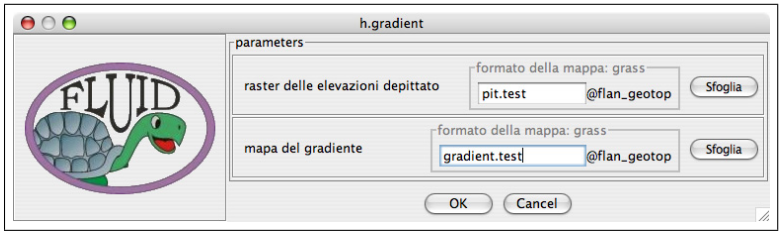

Figure 3.20: *h.gradient. Dialog box where the names of the input and output maps are specified.*

The result of the processing operation is shown in figure 3.21.

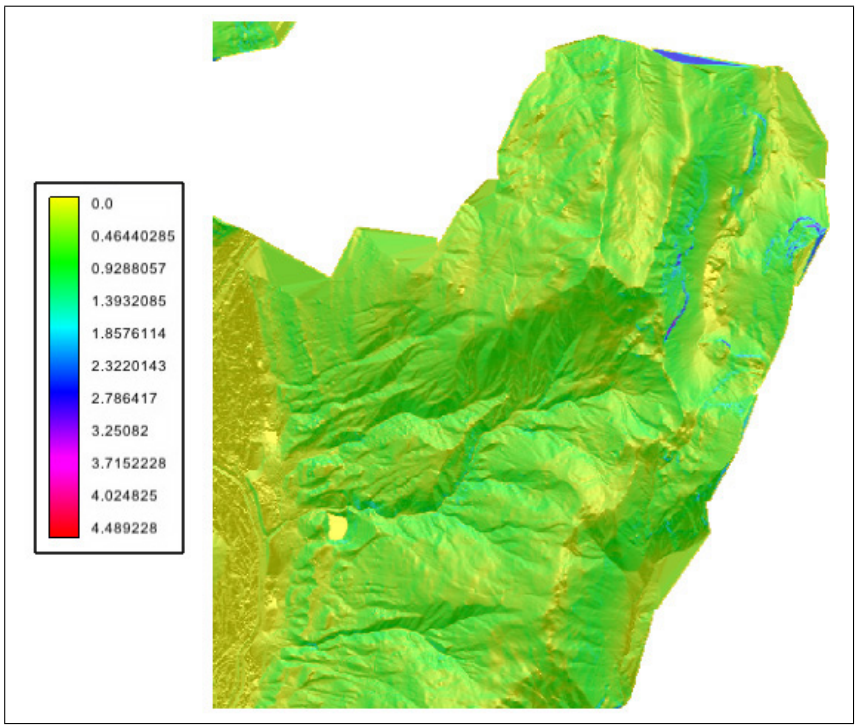

Figure 3.21: *h.gradient. Gradient map. The Flanginec Basin.*

Calculation of the Network

The network can now be calculated by imposing a threshold value on the product of the contributing area and the gradient. Click the *h.extractnetwork* icon so that the command's graphic interface appears; select the second execution mode and input the information necessary to the calculation. The required input data are, in order: the drainage directions map, the contributing areas map, the slope map, calculated with *h.gradient*, and the threshold value. In this case, as in the last, the threshold value is chosen on the basis of the land area being analyzed and the map resolution. Figure 3.22 shows the command's graphic interface where the names of the input and output maps are specified. The result of the network extraction process is shown in figure 3.23.

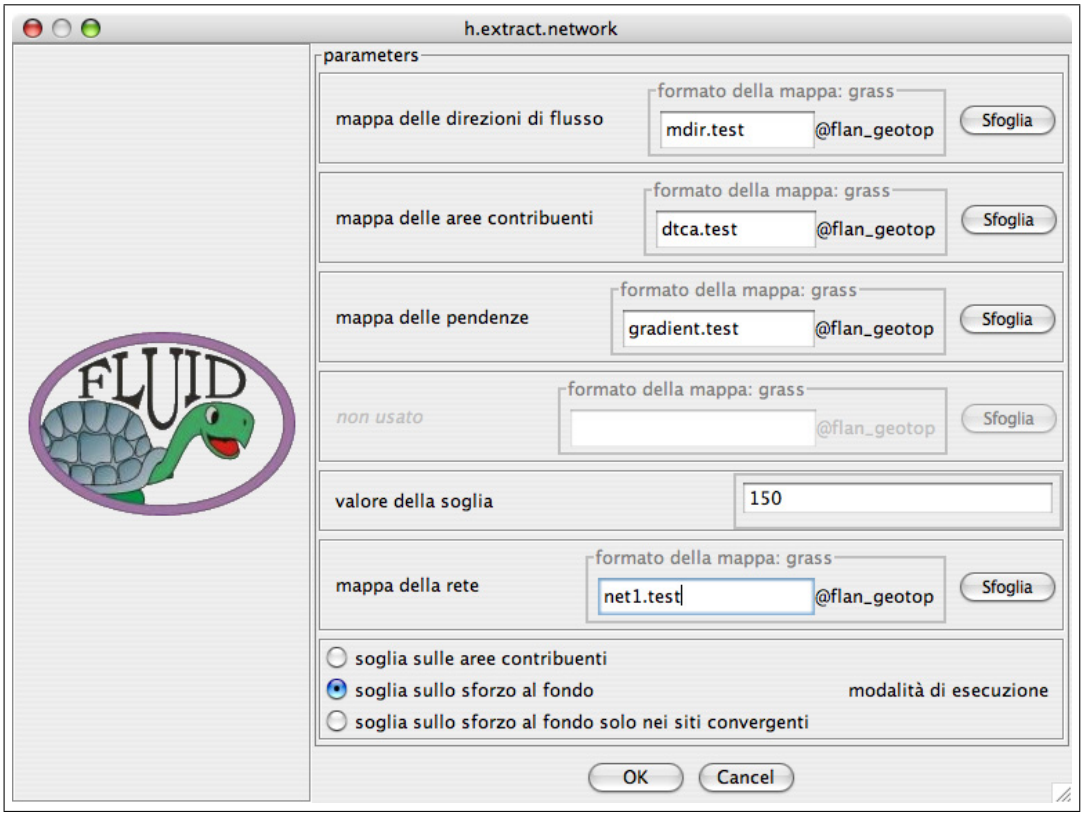

Figure 3.22: *h.extractnetwork. Dialog box where the names of the input and output maps are specified.*

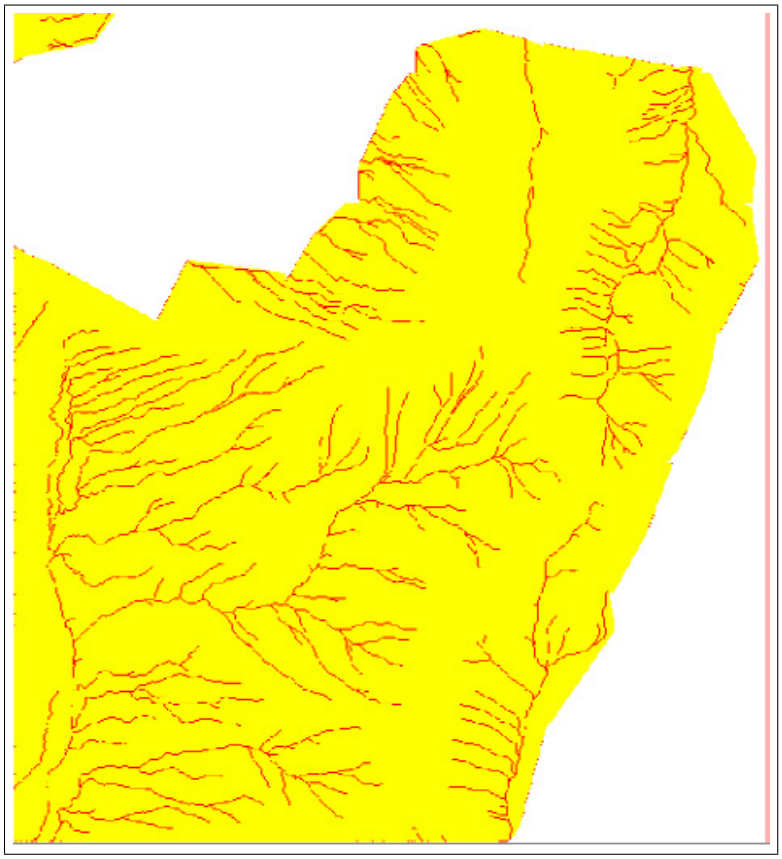

Figure 3.23: *h.extractnetwork. Map of the hydrographic network obtained by imposing a threshold on the product of the contributing areas and the gradient. The Flanginec Basin.*

3.5.3 Determination of the Network Using the Curvatures

The hydrographic network is extracted considering only the concave points as belonging to the network. As in the first case, a threshold value is imposed on a map. To identify the concave points it is necessary to calculate the curvatures (tangent, profile, and planar) and then execute *Topological classes* in order to distinguish between concave, planar, and convex points.

Curvature

This program calculates the planar, profile, and tangent curvatures of an area. The curvatures represent the deviation of the gradient vector per unit length (in radians) along particular curves traced on the surface under study. For further details please refer to *The Horton Machine* [2].
The command to execute is *h.curvatures*, from the main menu select:

HortonMachine ⇒ *Basic topographic attributes* ⇒ *h.curvatures*

or else click the corresponding icon from the toolbar that appears by checking:

HortonMachine ⇒ *Basic topographic attributes*

The toolbar with the *h.curvatures* icon is shown in figure 3.24.
The *h.curvatures* command can also be executed from the console command line:
h.curvatures [–quiet] [–verbose] [–version] [–usage] –pit <pit> –pitmapset <pitmapset> [–pitformat <pitformat>] –prof_curv <prof_curv> –prof_curvmapset <prof_curvmapset> [–prof_curvformat <prof_curvformat>] –plan_curv <plan_curv> –plan_curvmapset <plan_curvmapset> [–plan_curv format <plan_curvformat>] –tang_curv <tang_curv> –tang_curvmapset <tang_curvmapset> [–tang_curvformat <tang_curvformat>] [–usegui]

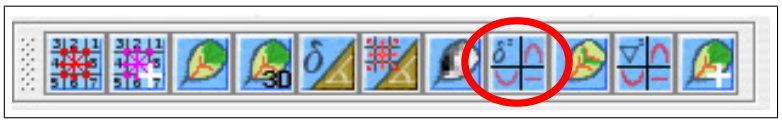

Figure 3.24: *The* h.curvatures *icon.*

Example

The curvatures are to be calculated. The required input is the depitted elevation map, calculated with *h.pitfiller*. In figure 3.25 the dialog box where the names of the input map and output maps are specified, the resulting output maps are shown in figure 3.26.

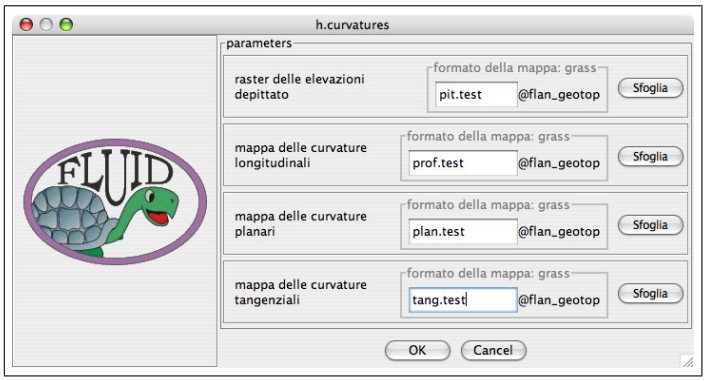

Figure 3.25: *h.curvatures. Dialog box where the names of the input and output maps are specified.*

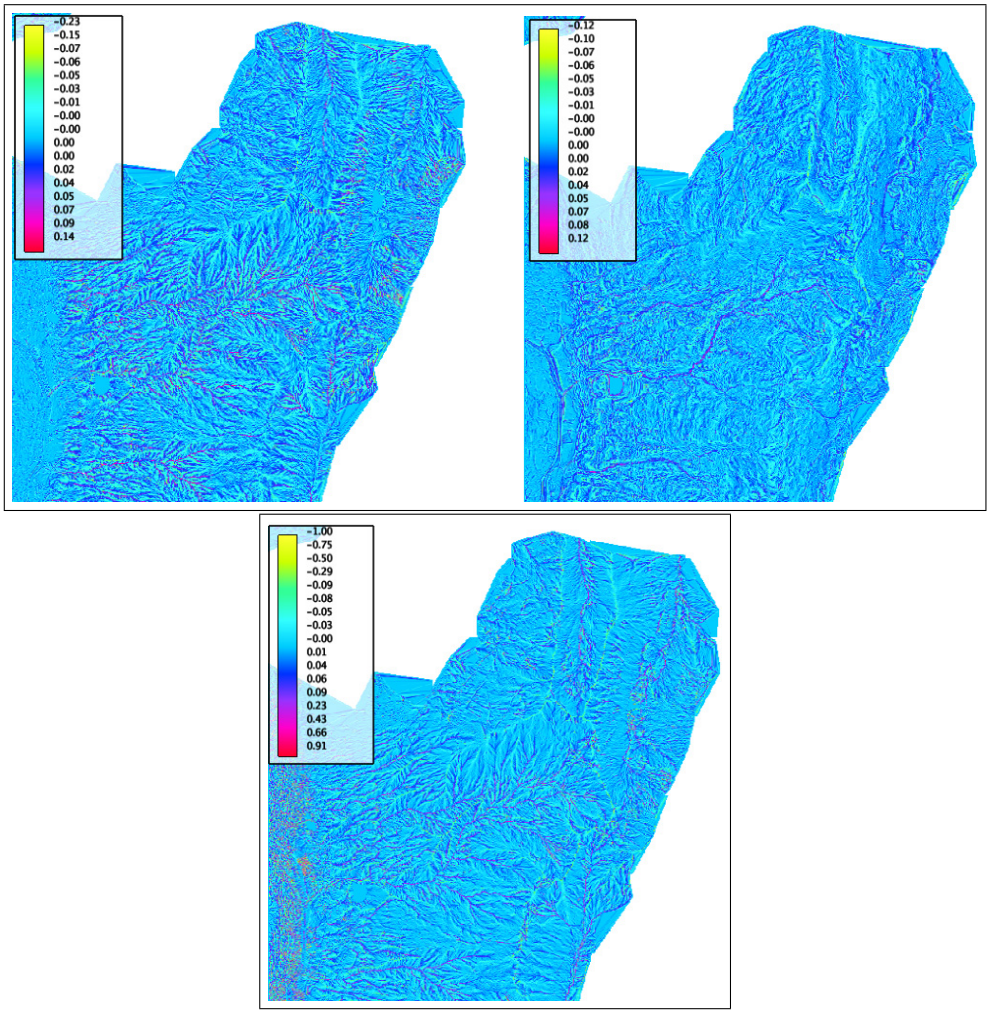

Figure 3.26: *h.curvatures. Map of the tangent curvature (left), profile curvature (right), and planar curvature (bottom) of the Flanginec Basin.*

Tc

Topological Classes classifies a land surface area, subdividing it into 9 topographic classes on the basis of the profile and planar curvature [see *The Horton Machine* [2]]. From these 9 classes the program then reclassifies the map, grouping the planar, concave, and convex sites into three categories. The program requires you to impose a threshold value on the profile curvature and the tangent curvature (those sites with an absolute curvature value less than the value of the threshold are considered planar). In general, in order to determine this value experiments are carried out for every basin, depending on the topography.
The adopted conventions for the description of the topological classes are:

- 10 → planar sites - parallel;
- 20 → convex sites - parallel;
- 30 → concave sites - parallel;
- 40 → planar sites - divergent;
- 50 → convex sites - divergent;
- 60 → concave sites - divergent;
- 70 → planar sites - convergent;
- 80 → convex sites - convergent;
- 90 → concave sites - convergent.

for the map where the 9 classes are grouped into 3 fundamental ones, the adopted conventions are the following:

- 15 → concave sites (classes 30, 70, 90);
- 25 → planar sites (class 10);
- 35 → convex sites (classes 20, 40, 50, 60, 80).

Figure 3.27 shows the subdivision of the map pixels according to the adopted convention.

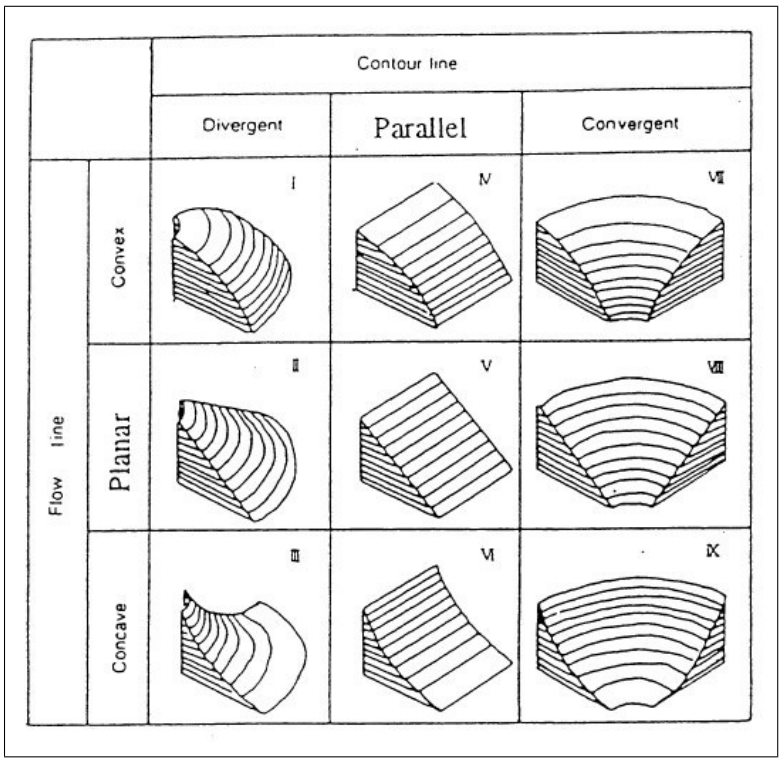

Figure 3.27: *Subdivision of the pixels by curvature.*

The command to execute is *h.tc*. From the main menu select:

$$HortonMachine \Rightarrow Hillslope\ analyses \Rightarrow h.tc$$

or else click the corresponding icon from the toolbar that appears by checking:

$$HortonMachine \Rightarrow Hillslope\ analyses$$

The toolbar with the *h.tc* icon is shown in figure 3.28.

Figure 3.28: *The* h.tc *icon.*

The *h.tc* command can also be executed from the console command line:
h.tc [–quiet] [–verbose] [–version] [–usage] –prof_curv <prof_curv> –prof_curvmapset <prof_curvmapset> [–prof_curvformat <prof_curvformat>] –tang_curv <tang_curv> –tang_curvmapset <tang_curvmapset> [–tang_curvformat <tang_curvformat>] –cp3map <cp3map> –cp3mapmapset <cp3mapmapset> [–cp3mapformat <cp3mapformat>] –cp9map <cp9map> –cp9mapmapset <cp9mapmapset> [–cp9mapformat <cp9mapformat>] –th_prof <th_prof> –th_tan <th_tan> [–usegui].

Example

The execution of the command requires as input the curvature maps, calculated with *h.curvatures*. The command's graphic interface, where the names of the input and output maps are specified, is shown in figure 3.29. The resulting output maps are shown in figures 3.30 and 3.31.

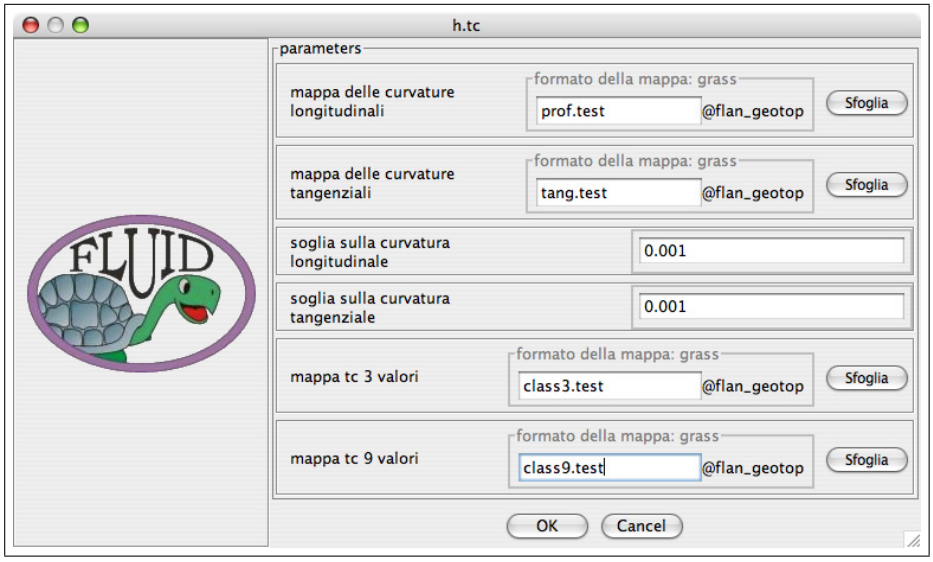

Figure 3.29: *h.tc. Dialog box where the names of the input and output maps are specified.*

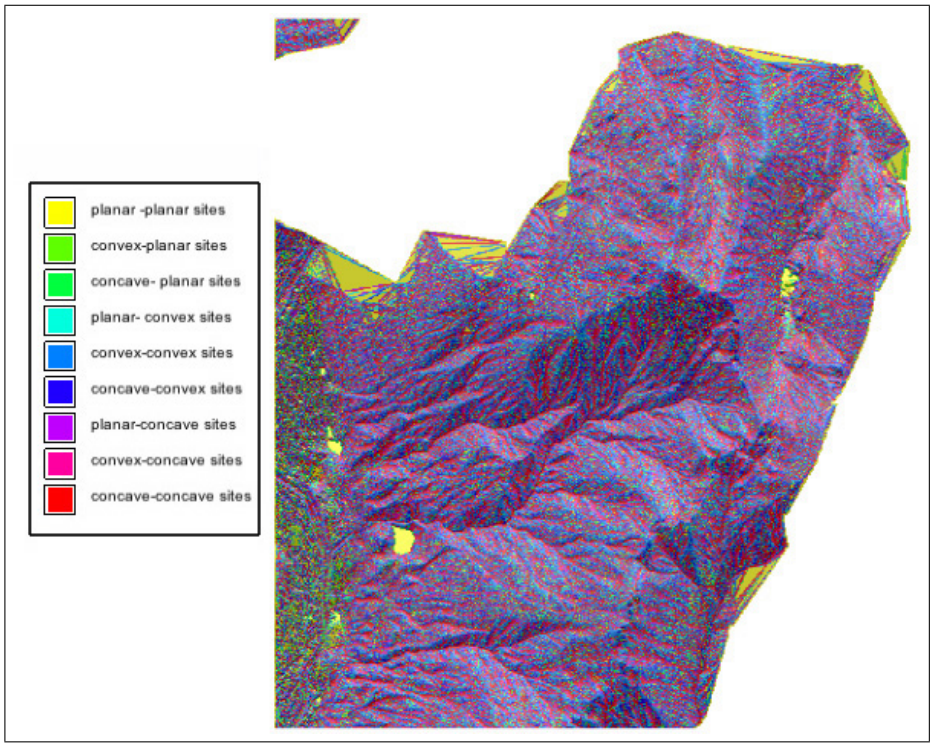

Figure 3.30: *h.tc. Map of the topological classes, with classification according to 9 categories.*

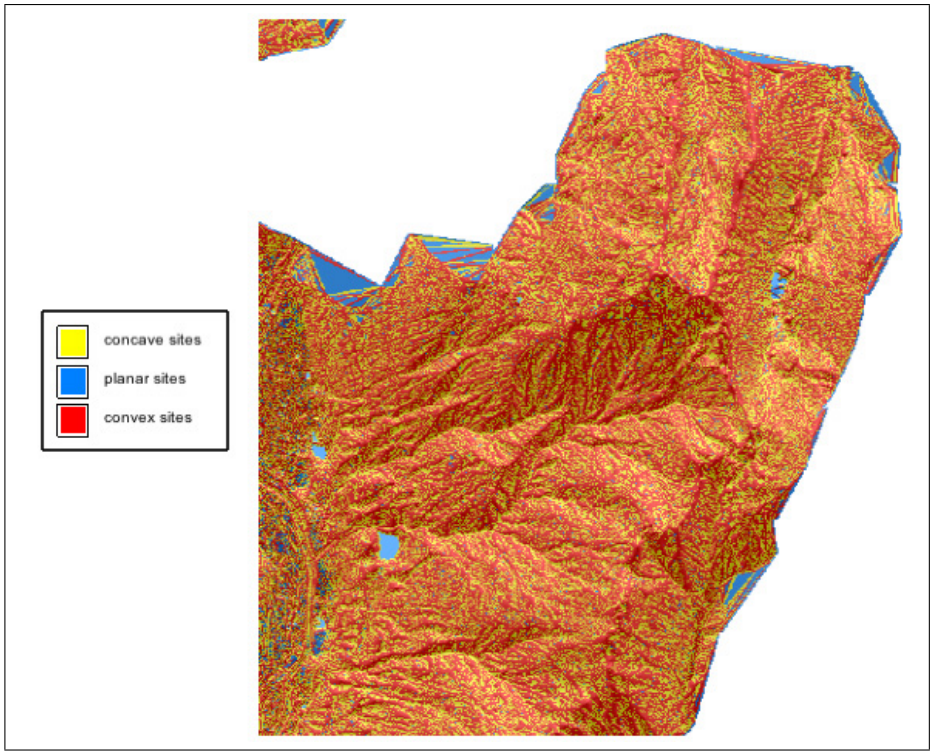

Figure 3.31: *h.tc. Map of the topological classes, reclassified according to 3 categories. The concave sites are marked in yellow, the convex sites are marked in red, and the planar ones are in blue.*

Extraction of the Hydrographic Network

Once the concave, convex, and planar sites have been distinguished the extraction of the hydrographic network is possible using the third available method. In this case, also, a threshold value is imposed on a map, in the example the contributing areas map is used, but one could use, for example, the map of area to slope ratio (this map can be generated quite easily with the *r.mapcalc* command, for further details about this command refer to the JGrass [1]).

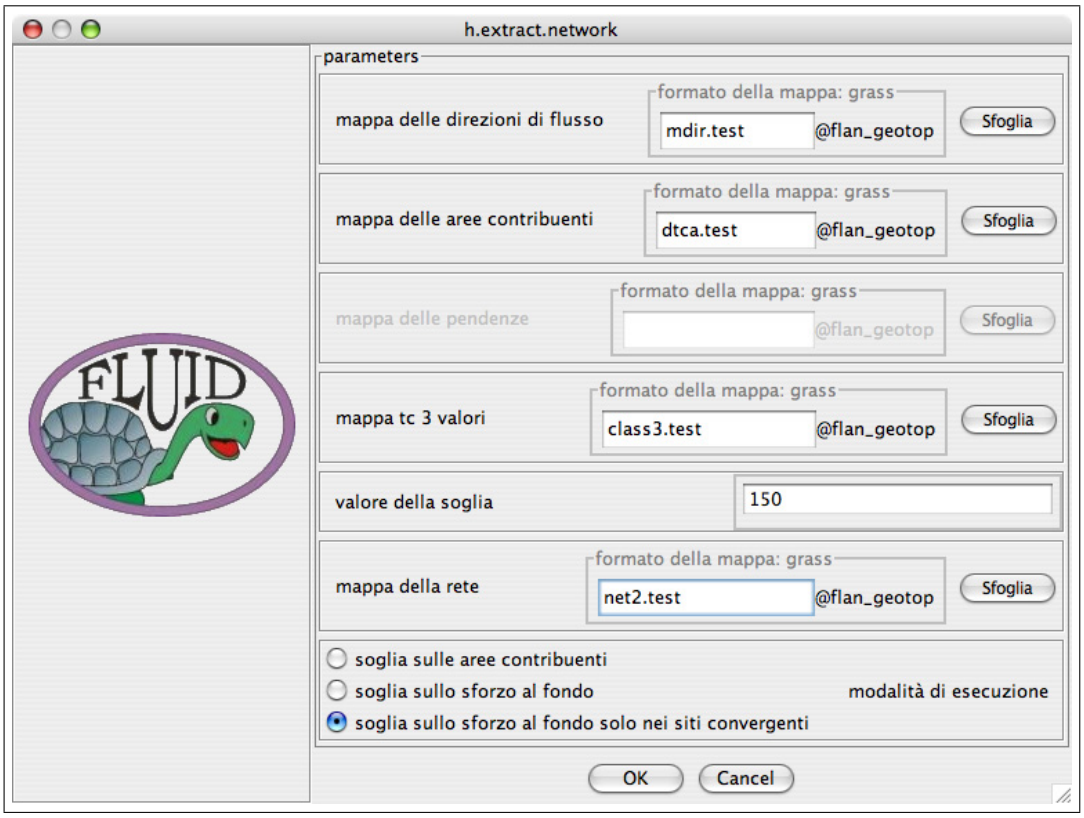

Figure 3.32: *h.extractnetwork. Dialog box where the names of the input and output maps are specified.*

The result of the choices made is shown in figure 3.33.

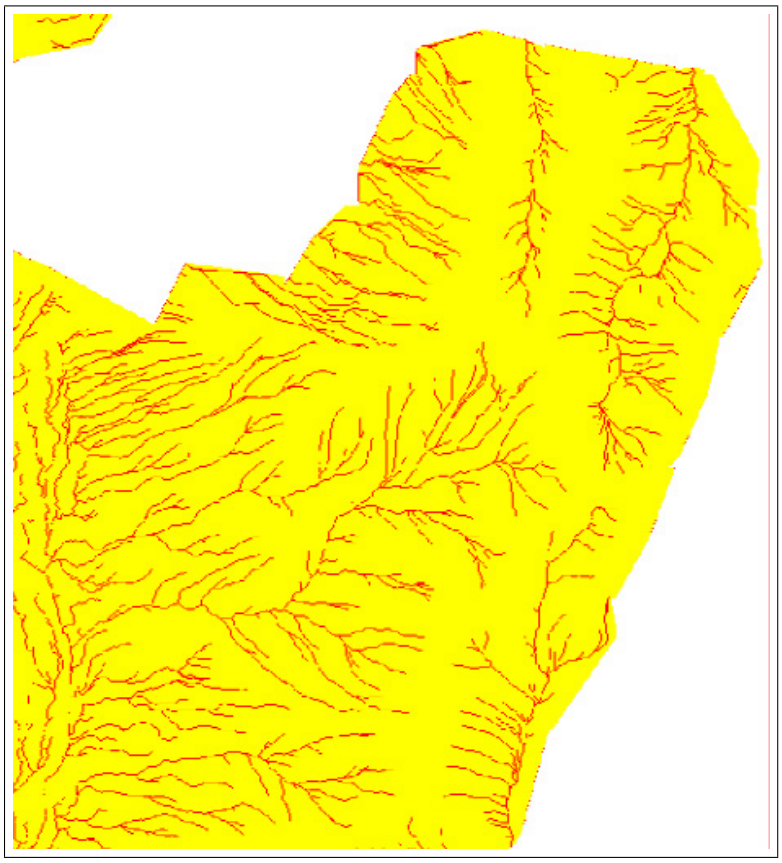

Figure 3.33: *h.extractnetwork. Map of the hydrographic network obtained by imposing a threshold value on the contributing areas. The Flanginec Basin.*

4 Extraction of the Basin of Interest

4.1 WaterOutlets

Once the hydrographic network has been identified, with the aid of one of the methods described in the previous chapter, it is possible to extract the catchment area of interest (which is only a part of the territory analyzed up to this point) and proceed to its geomorphological analysis. The program for the extraction of the basin requires the closing section to be specified. The closing section must belong to the channel network, in other words, it must be a channel pixel.
The command to execute is *h.wateroutlet*. From the main menu select:

HortonMachine ⇒ *DEM manipulation* ⇒ *h.wateroutlet*

or else click the corresponding icon from the toolbar that appears by checking:

HortonMachine ⇒ *DEM manipulation.*

Figure 4.1: *The* h.wateroutlet *icon.*

The *h.wateroutlet* command can also be executed from the console command line:
h.wateroutlet [–quiet] [–verbose] [–version] [–usage] –drainage <drainage> –basin <basin> –northing <northing> –easting <easting> [–extractmap <extractmap>] [–usegui]

Example

To execute the command, click the corresponding icon and so display the command's graphic interface. The required input data are the drainage directions map and the coordinates of the closing section. The preliminary operation is to identify the closing section of the basin to be extracted. If its coordinates are already known it is sufficient to input them in the appropriate text boxes. In the case that the coordinates are not known it will be necessary to view the hydrographic network before launching *h.wateroutlet*. Input the name of the hydrographic network map in the

dialog box, as shown in figure 4.2 (in the example the network map is *net.test*). The program allows you to click on the map and returns the value of the selected point. The closing section of the basin is necessarily part of the channel network, it therefore must return a value of 2 (according to the adopted convention, channel sites have a value of 2 to distinguish them from slope sites). Figure 4.2 shows the program window.

The *WaterOutlets* program generates two output files, one containing a mask of the extracted basin (that is, a raster with a value of 1 in correspondence of the extracted basin and a null value beyond the basin limits), and a second file containing a map trimmed along the mask boundary. It is possible to choose the map to trim, from among all the maps generated previously, by inputting the map name in the appropriate space (beside the string *the map to extract*). In this example case, it was decided to extract the depitted DEM, calculated with *h.pitfiller*. The program will assign the trimmed map a compound name made up of the name of the original map and the name of the mask, in the example the resulting map is called *pit.test.m*. Figure 4.3 shows the mask of the Flanginec Basin superimposed onto the hydrographic network map, figure 4.4 shows the trimmed DEM.

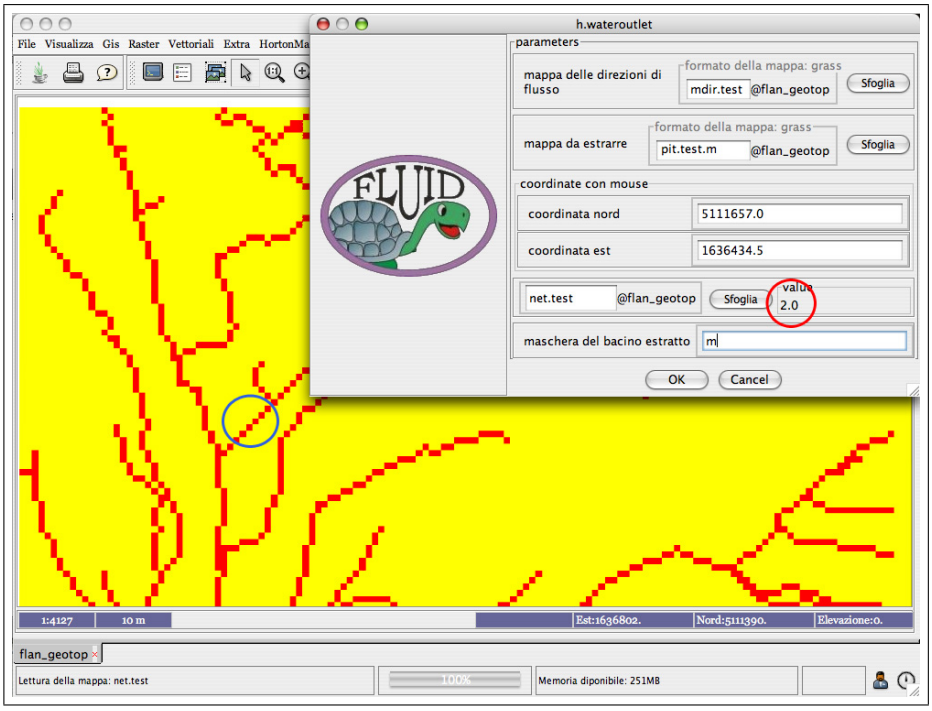

Figure 4.2: *h.wateroutlet. Dialog box requiring the names of the input maps and the closing section coordinates. The blue circle marks the area where the closing section was chosen. The red circle shows the value of the network map in correspondence of the selected point (the value is 2 therefore the point is effectively part of the channel network).*

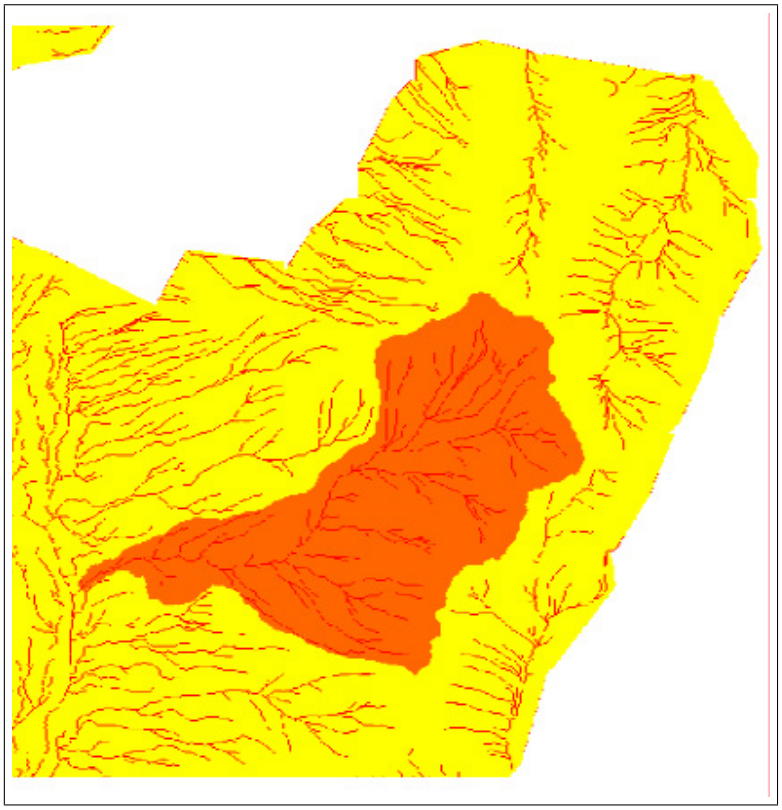

Figure 4.3: *h.wateroutlet. Mask of the extracted subbasin superimposed onto the channel network map. The Flanginec Basin.*

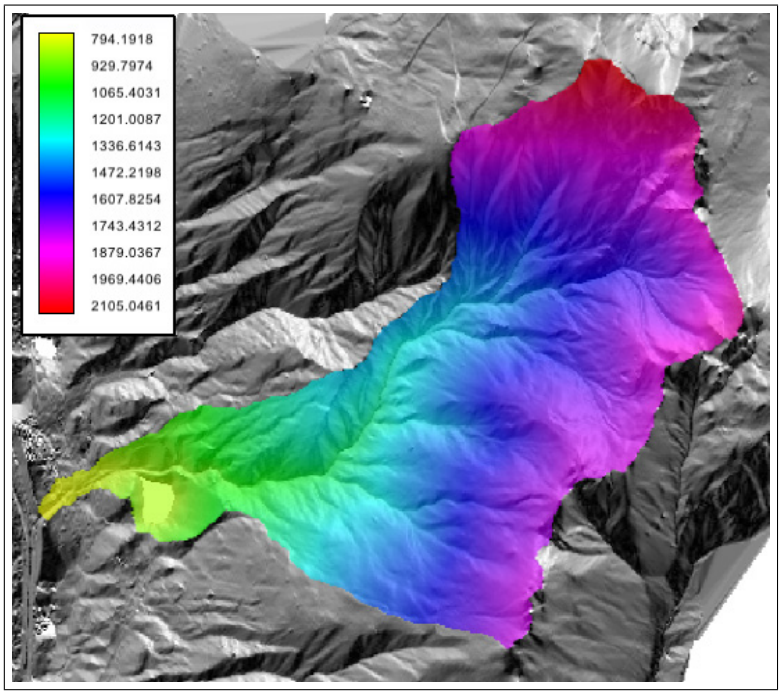

Figure 4.4: *h.wateroutlet. Map of the extracted subbasin. The Flanginec Basin.*

5 Input Maps for GEOtop

Once the basin of interest has been extracted, it is possible to extract the maps necessary for the execution of GEOtop.

5.1 Format of the Input Files

GEOtop requires the input maps to have a particular format called *Fluidturtle* (see the GEOtop Manual). With JGrass it is possible to generate the maps directly in this format. These input files are ASCII files with a header containing details about the region (resolution, coordinates, and number of points that make up the map). Here is an example:

```
/** Created by h.pitfiller from the map:  DTM */
index {3}
1:  float array header {10.0,10.0,5110090.0,1635940.0}
2:  float array novalue {-1,-9999.0}
3:  double matrix pit {640,580}
```

The first line is a comment that the program does not read, it contains information about the origin of the file. In the example the comment states that the map was created with *h.pitfiller* using the map *DTM* as input.
The string `index{3}` specifies the number of blocks of data in the file, in this case 3.
The first data block has information about the region in question:

- `10.0,10.0` are the pixel dimensions, in metres;
- `5110090.0,1635940.0` are the coordinates of upper left corner of the map.

The term "*float array*" means that the data are floating points and they are contained in an array, which in *Fluidturtles* jargon means: a data set of unspecified length contained between two {}. "*header*" is the name of these data, while "*novalue*" is the name of the second data block. The

second block gives the value assigned to the map in those points where the real value is not known. When the program comes across this value it omits the corresponding point from the calculations. In this case the "*novalue*" value is -9999.0. The *-1* before it means that the "*novalue*" value is less than all other values contained in the raster. To understand what a *novalue* is, it is worth remembering, for example, that when the basin of interest was extracted in chapter 4 the points external to the basin of interest were eliminated, in these points the map has no value.
The third block contains the number of rows and columns of the data matrix, in the example there are 640 rows and 580 columns. In the example the data matrix itself is not shown.
For further details please refer to *The Horton Machine* [2].

5.2 Creation of the Input Maps for GEOtop

GEOtop requires the following input maps for its execution to be possible:

- depitted elevation map, (*h.pitfiller*);
- drainage directions map, (*h.flowdirections, h.draindir*);
- contributing areas map, (*h.draindir*);
- channel network map, (*h.extractnetwork*);
- gradient map, (*h.gradient*);
- map of the slopes calculated along the drainage directions, (*h.slope*);
- map of the laplacian (nabla operator), (*h.nabla*);
- aspect map, (*h.aspect*);
- map of the distance to outlet of every point, (*h.D2O*);
- map of the drainage directions with a value of 10 in correspondence of the channel network (*Channel Network*).

Some of the maps listed have been calculated already, however, they will need to be trimmed along the border of the mask of the extracted subbasin so as to carry out an analysis only of the basin of interest. This operation can be carried out with the *r.mapcalc* command.
To execute *r.mapcalc*, from the main menu select:

Raster $\Rightarrow$ *Operations on raster maps* $\Rightarrow$ *r.mapcalc*

In order to carry out the required calculations you will need to input an expression of the type:

new_map = if(condition fulfilled, then assign null value, else assign value from map)

to trim the drainage directions map the expression to input is:

$$\text{dir.test.m} = \text{if}(\$m\$ == \text{null}, \text{null}, \text{dir.test})$$

in this way a map is generated, in the specific case called *dir.test.m*, with a "null value" in correspondence of a "null value" in the map called *m* (*m* is the mask, see chapter 4, and so the new map has null values outside the basin of interest), in the other points of the new map (within the basin of interest) the value assigned is that of the drainage directions map (*dir.test*). The *r.mapcalc* graphic interface is shown in figure 5.1, while figure 5.2 shows the resulting map.

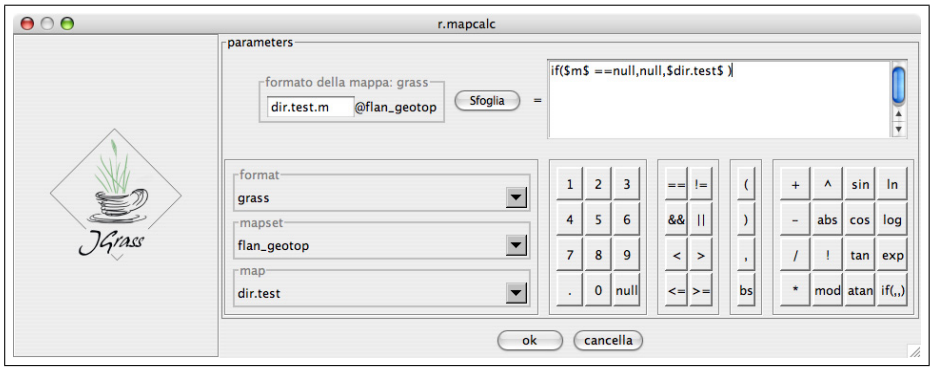

Figure 5.1: *r.mapclac. Command window where the expression to be calculated is input.*

Once the drainage directions map of the basin of interest has been obtained it is necessary to mark the basin outlet. This is done with the *h.markoutlets* command, using the new drainage directions map, just calculated, as input. In order to trim the other maps you only need to repeat the procedure that has just been described.

Once the maps have been trimmed the commands that have not yet been described can be presented. These commands allow you to calculate a set of parameters that describe the hydrographic basin.

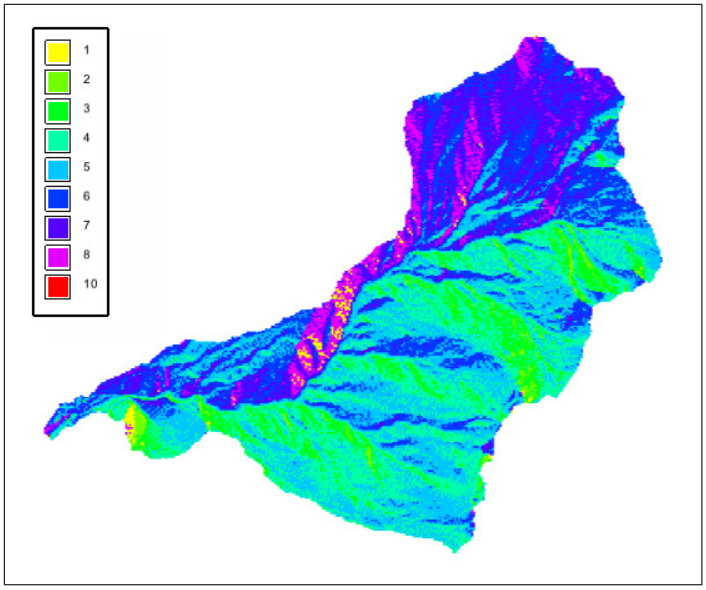

Figure 5.2: *h.draindir. Map of the corrected drainage directions of the extracted basin. The Flanginec Basin.*

There now follows a series of maps that were calculated earlier but that have been recalculated considering only the basin of interest.

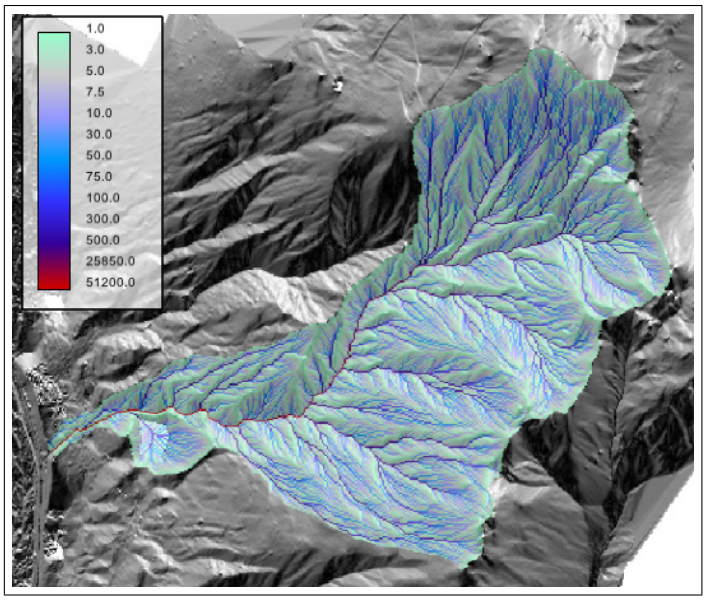

Figure 5.3: *h.draindir. Total contributing areas map of the extracted basin. The Flanginec Basin.*

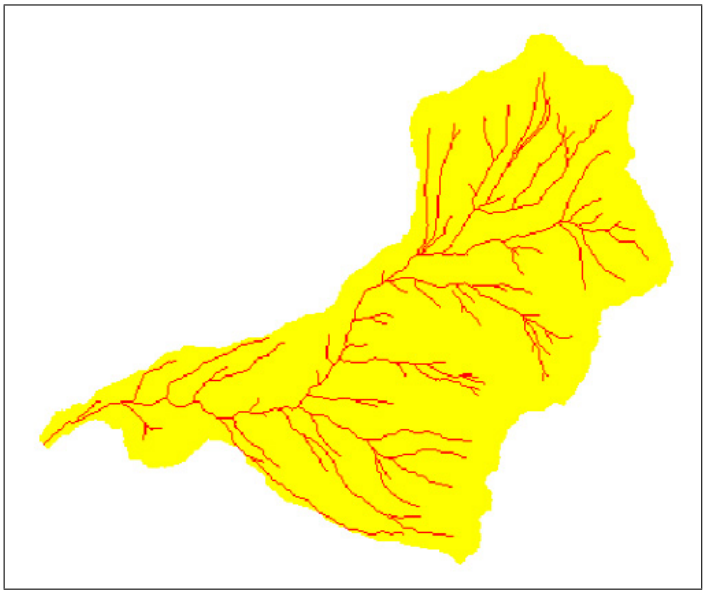

Figure 5.4: *h.extractnetwork. Map of the channel network. The Flanginec Basin.*

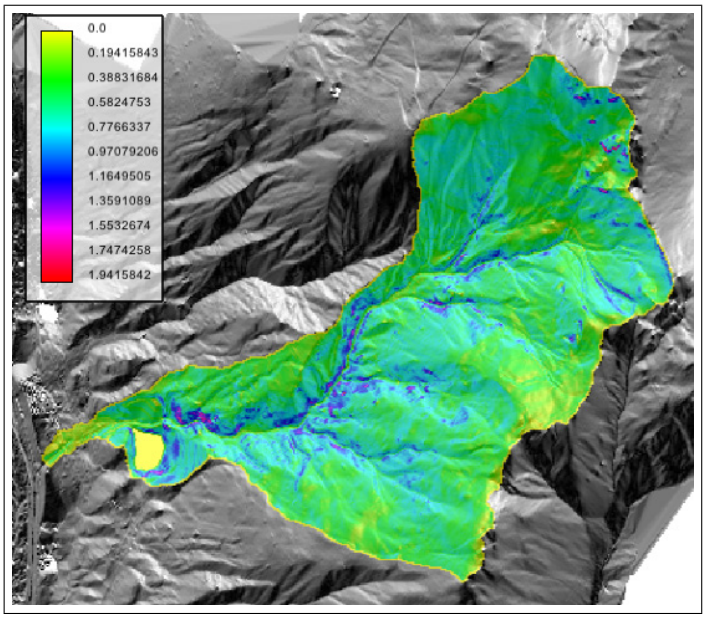

Figure 5.5: *h.gradient. Map of the gradient of the extracted basin. The Flanginec Basin.*

5.2.1 Slope

We now proceed to calculate the slopes along the drainage directions, these differ from the slopes calculated with *h.gradient* as specified in *The Horton Machine* [2]. The command to execute is *h.slope*. From the main menu select:

HortonMachine ⇒ *Basic topographic attributes* ⇒ *h.slope*

or else click the corresponding icon from the toolbar that appears by checking:

HortonMachine ⇒ *Basic topographic attributes*

The toolbar with the *h.slope* icon is shown in figure 5.6.

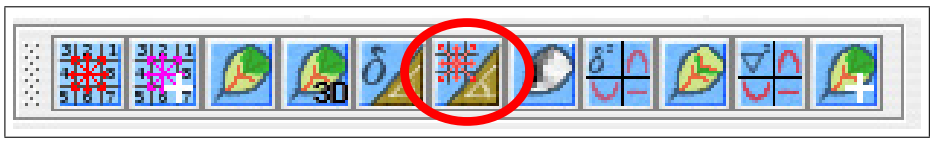

Figure 5.6: *The* h.slope *icon.*

The *h.slope* command can also be executed from the console command line:
h.slope [–quiet] [–ver>bose] [–version] [–usage] –pit <pit> –pitmapset <pitmapset> [–pitformat <pitformat>] –flow <flow> –flowmapset <flowmapset> [–flowformat <flowformat>] –slope <slope> [–slopemapset <slopemapset>] [–slopeformat <slopeformat>] [–usegui]

Example

The command is executed in the way described above, however, the format of the output maps must be specified. The required input maps are the DEM and the drainage directions map trimmed along the border (mask) of the extracted catchment basin. To select the output format, in the third line of the dialog box, were the name of the slope map is required, click *Browse*. From the dropdown menu of the window that appears select the *fluidturtleascii* format and click *next*. Type the name of the map to be created (the input box will become active once a mapset has been selected). Some example images now follow.

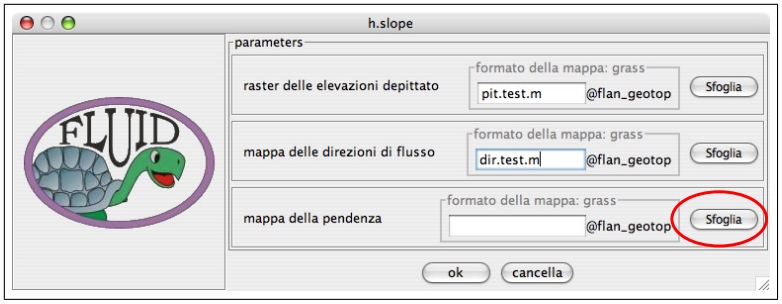

Figure 5.7: *h.slope. Dialog box where the names of the input and output maps are specified.*

Figure 5.8: *h.slope. Choosing the output map format. The Flanginec Basin.*

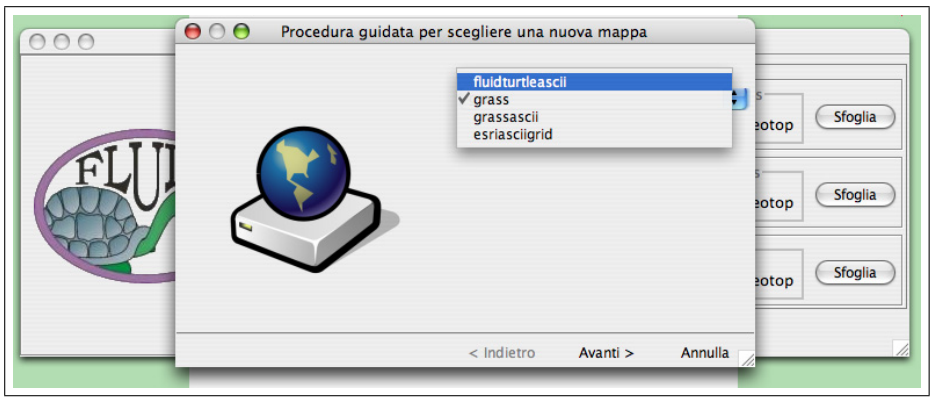

Figure 5.9: *h.slope. Choosing the output map format. The Flanginec Basin.*

Figure 5.10: *h.slope. Naming the output map to be generated. The Flanginec Basin.*

The map will be created and saved in a directory called *fluidturtleascii* in the mapset of origin. The file can be used directly in GEOtop. A plot of the resulting map is shown in figure 5.11.

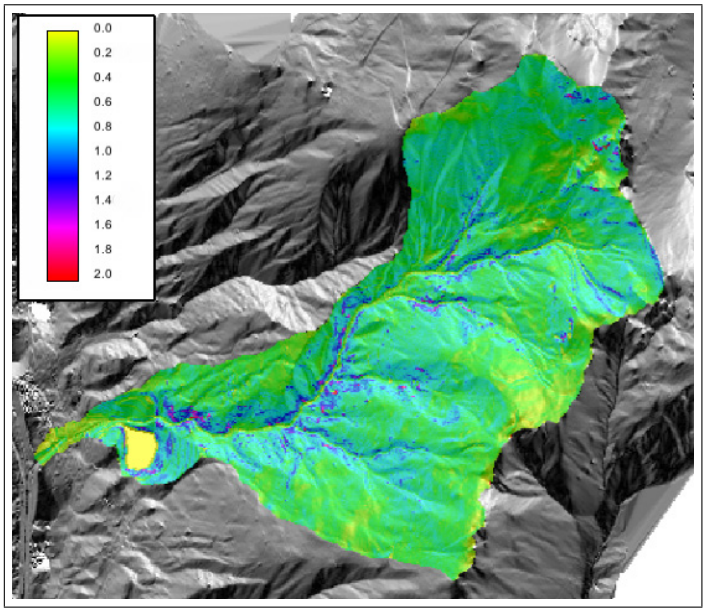

Figure 5.11: *h.slope. Map of the slopes calculated along the drainage directions. The Flanginec Basin.*

5.2.2 Nabla (Laplacian)

The Laplacian of the elevation ($\nabla^2 z$) will now be calculated. The program gives the choice between either calculating the Laplacian in every point of the map or generating a map that distinguishes between concave sites , $\nabla^2 z < 0$, convex sites, $\nabla^2 z > 0$, and planar sites $|\nabla^2 z| < \epsilon$, by imposing a threshold value, ϵ, to the value of the Laplacian. For further details please refer to *The Horton Machine* [2]. GEOtop requires the site classes and not the specific values of the Laplacian in the various parts of the map. The command to execute is è *h.nabla*. From the main menu select:

HortonMachine ⇒ *Basic topographic attributes* ⇒ *h.nabla*

or else click the corresponding icon from the toolbar that appears by checking:

HortonMachine ⇒ *Basic topographic attributes*

The toolbar with the *h.nabla* icon is shown in figure 5.12.

Figure 5.12: *The* h.nabla *icon.*

The *h.nabla* command can also be executed from the console command line:
h.nabla [–quiet] [–verbose] [–version] [–usage] –pit <pit> –pitmapset <pitmapset> [–pitformat <pitformat>] –nabla <nabla> –nablamapset <nablamapset> [–nablaformat <nablaformat>] –mode <mode> –th_nabla <th_nabla> [–usegui]

Example

The distinction between concave and convex sites is determined, in this specific case, by imposing a threshold value ϵ of 0.001. The value itself is to be chosen in reference to the local topography. In order to obtain a map that distinguishes the three classes, the command must be executed in *CLASSES* mode. The dialog box where the names of the input and output maps are specified is shown in figure 5.13. The result of the process is shown in figure 5.14.

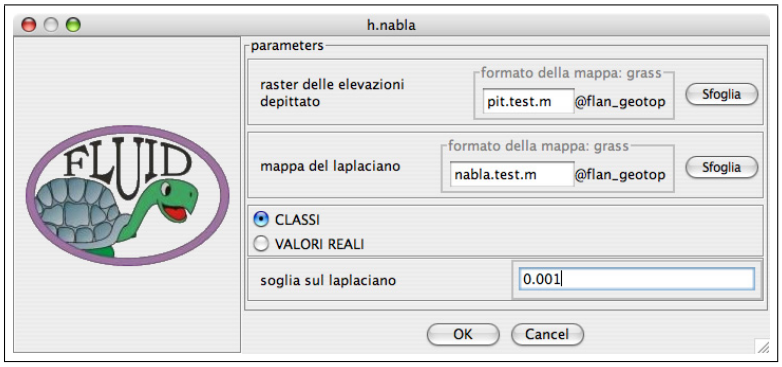

Figure 5.13: *h.nabla. Dialog box where the names of the input and output maps are specified.*

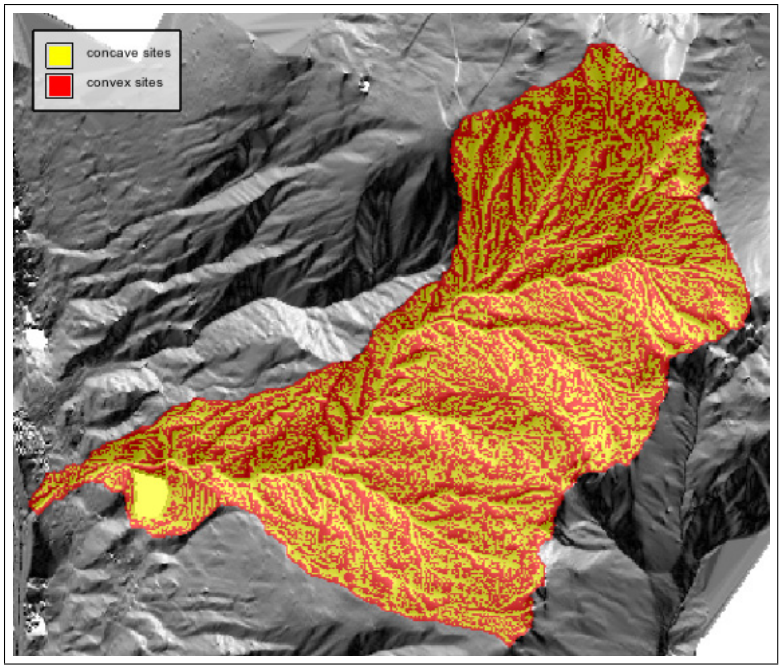

Figure 5.14: *h.nabla. Map of the Laplacian, distinguishing between concave, convex, and planar sites. The Flanginec Basin.*

5.2.3 Aspect

At this stage the aspect of the local area must be determined. The aspect is defined as the angle of inclination of the gradient, calculated in degrees. For further details about the method please refer to *The Horton Machine* [2]. The command to execute is *h.aspect*. From the main menu select:

HortonMachine ⇒ *Basic topographic attributes* ⇒ *h.aspect*

or else click the corresponding icon from the toolbar that appears by checking:

HortonMachine ⇒ *Basic topographic attributes*

The toolbar with the *h.aspect* icon is shown in figure 5.15.

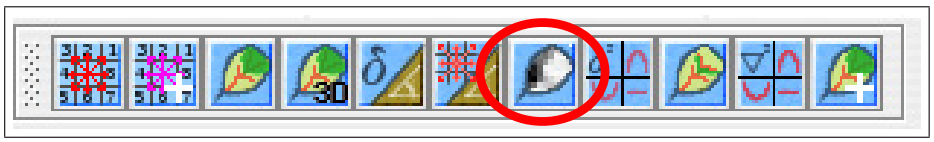

Figure 5.15: *The* h.aspect *icon.*

The *h.aspect* command can also be executed from the console command line:
h.aspect [–quiet] [–verbose] [–version] [–usage] –pit <pit> –pit <pit> –pitmapset <pitmapset> [–pitformat <pitformat>] –aspect <aspect> –outmapset <outmapset> [–outputformat <outputformat>] [–usegui]

Example

The dialog box requiring the names of the input and output maps is shown ion figure 5.16. The resulting output map is shown in figure 5.17.

Figure 5.16: *h.aspect. Dialog box where the names of the input and output maps are specified.*

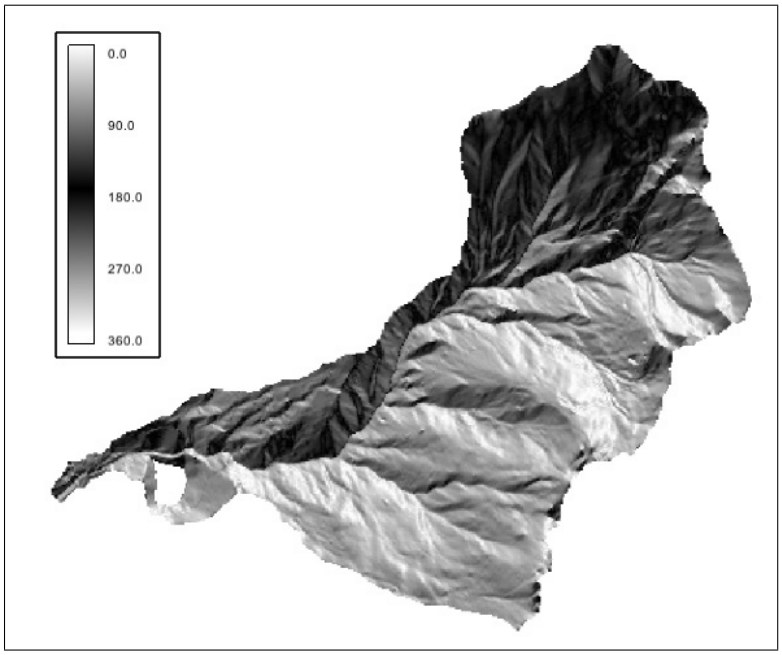

Figure 5.17: *h.aspect. The aspect map. The Flanginec Basin.*

5.2.4 Dist2Outlets

GEOtop then needs the map showing the distance of every pixel from the outlet, following the drainage directions (in order to calculate the amplitude function). JGrass gives the choice to calculate the distance either in metres or in number of pixels. GEOtop needs the distance expressed as number of pixels.
The command to execute is *h.D2O*. From the main menu select:

HortonMachine ⇒ *Network related measures* ⇒ *h.D2O*

or else click the corresponding icon from the toolbar that appears by checking:

HortonMachine ⇒ *Network related measures*

The toolbar with the *h.D2O* icon is shown in figure 5.18.

Figure 5.18: *The* h.D2O *icon.*

The *h.D20* command can also be executed from the console command line:
h.D2O [–quiet] [–verbose] [–version] [–usage] –flow <flow> –flowmapset <flowmapset> [–flowformat <flowformat>] –dist2outlet <dist2outlet> –dist2outletmapset <dist2outletmapset> [–dist2outletformat <dist2outletformat>] –mode <mode> [–usegui]

Example

To execute the command and calculate the number of pixels that separates each point from the basin outlet the *topological distance* option must be selected. An image of the graphic interface where the input and output map names are specified is shown in figure 5.19. Figure 5.20 shows a map of the distances to the outlet.

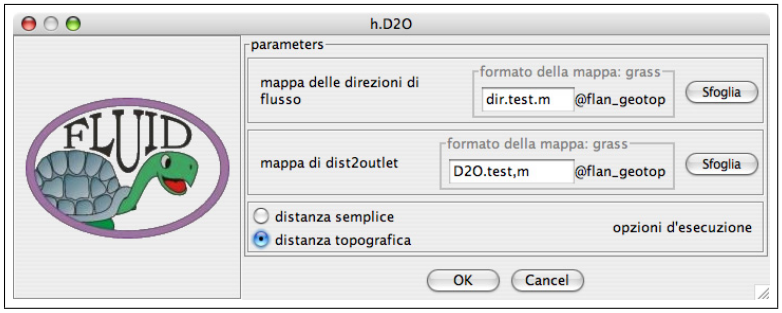

Figure 5.19: *h.D2O. Dialog box where the names of the input and output maps are specified.*

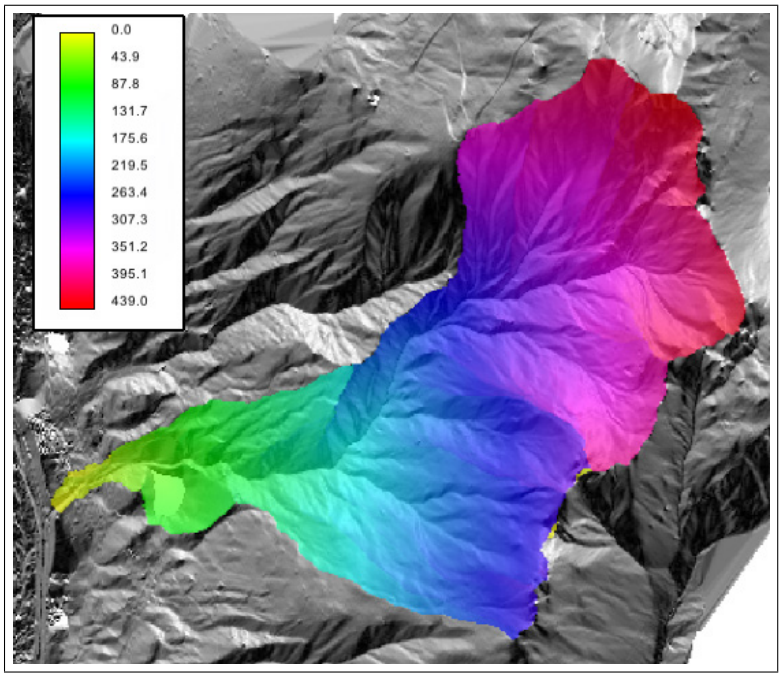

Figure 5.20: *h.D2O. Map of the distance of each point from the basin outlet. The Flanginec Basin.*

5.2.5 Channel Network

Finally, due to the particular way in which GEOtop works, it is necessary to mark the channel pixels as if they were closing sections of the basin, this is done by creating a map with a value of 10 in correspondence of the channel network and the corresponding values of the drainage directions in all the other points of the basin. This operation is carried out with the *r.mapcalc* command, which allows you to carry out mathematical operations on the maps. To call up the *r.mapcalc* dialog box, from the main menu select:

Raster ⇒ *Operations on raster maps* ⇒ *r.mapcalc*

it is possible to launch the command by clicking the icon that appears by checking:

Raster ⇒ *Raster Map Tools*

figure 5.21 shows the toolbar from which to select the *r.mapcalc* icon.

Figure 5.21: *The* r.mapcalc *icon.*

To obtain the desired map it is necessary to input an expression of the following type:

new map = if(channel netweork map == 2, 10, drainage directions map)

an explanation of the different terms of the expression now follows:

- *if(condition, then, else)*: if the condition is met then the first value is assigned, otherwise the second value is assigned. The condition is checked in every point of the channel network map.
- *channel network map == 2*: this indicates that only points belonging to the channel network are being sought (these are identified by the value 2, as explained in paragraph 3.18), these will be assigned the value 10 in the new map (10 is the value that is conventionally assigned to basin outlets);
- *10*: indicates the value that the points which fulfill the condition will be assigned in the new map;
- *drainage directions map*: indicates that the points which do not fulfill the condition will be assigned the value of the corresponding points of the drainage directions map.

Example

There now follows a calculation example, a new drainage directions map will be created with a value of 10 assigned to the channel network. In figure 5.22 there is an image of the graphic interface where the desired expression is inserted.

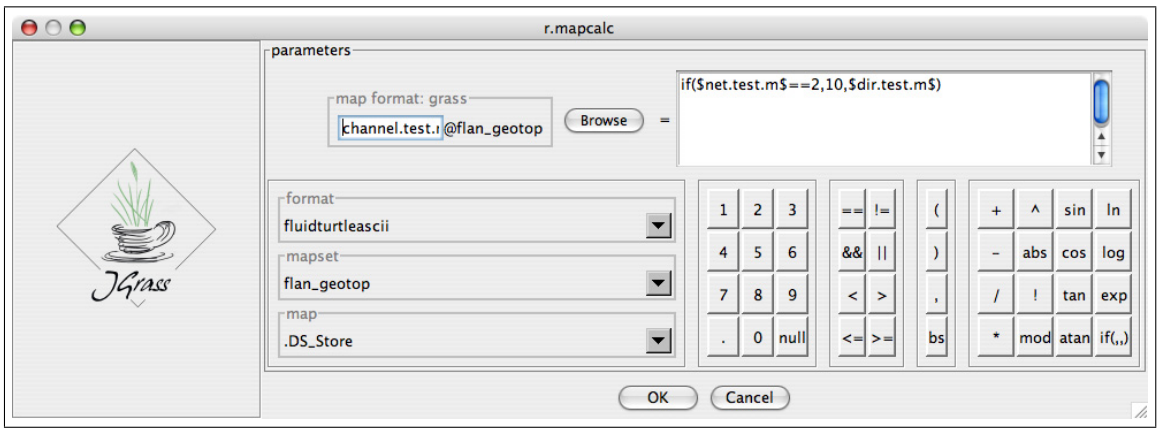

Figure 5.22: *The* r.mapcalc *graphic interface.*

In order to select the *fluidturtleascii* format for the output map, in the *format* area, select *fluidturtleascii* from the dropdown menu. Click *ok* to start the calculation process.
Figure 5.23 shows the resulting map.

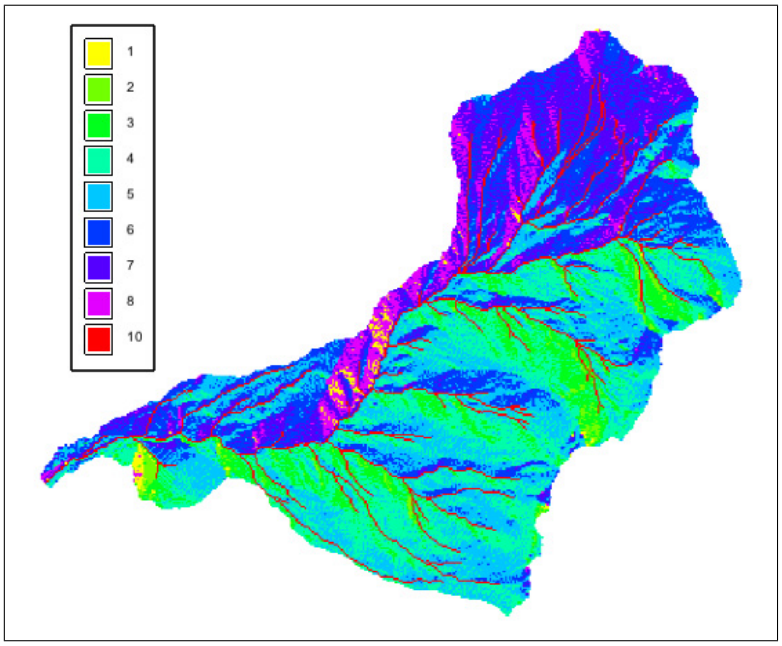

Figure 5.23: *Map of the drainage directions with 10 assigned in correspondence of the channel network. The Flanginec Basin.*

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